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Stress Corrosion Study of Carburized AISI 9310 and Carburized M-50 NiL Steels

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Space Administration
Office of Management
Scientific and Technical
Information Program

ACKNOWLEDGMENT

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INTRODUCTION

Bearing applications demand the use of hard steels for wear resistance. Unfortunately, increases in hardness result in brittleness and normally reduce the Stress Corrosion Cracking (SCC) resistance. In this program, an SCC investigation in a high humidity environment was undertaken on carburized AISI 9310 and carburized M-50 NiL steels. Carburized AISI 9310 steel is a proposed alternate to 440C steel for the bearing inner race in the Space Shuttle Main Engine (SSME) Alternate Turbopump Development (ATD) Program. Carburized M-50 NiL (Ni indicates nickel and L indicates low interstitials) may also find applications as a bearing alloy. The maximum sustained tensile stresses that these alloys can withstand in a highly humid environment were determined. The microstructure of the samples that failed was studied by metallography, and the fractures were studied by using Scanning Electron Microscopy (SEM) analysis. Since carburization usually has a great influence on mechanical properties [1], hardness determinations were performed at different distances from the case surface which served as an indication of the depth of carburization. Also, the corrosion properties of carburized AISI 9310 and carburized M-50 NiL were evaluated, as well as the suitability of Thin, Dense Chrome (TDC)—which can increase wear resistance on bearings—as a corrosion barrier.

EXPERIMENTAL PROCEDURE

The readings and measurements in this program were taken in English units and converted to SI units. The AISI 9310 steel per AMS 6265 [2] used in this evaluation was obtained from a vacuum melted, normalized, and tempered 3.81-cm (1.5-in) diameter bar. It was produced by Altech Company and supplied by Fry Steel Company. The M-50 NiL steel per AMS 6278 [3] was obtained from a vacuum induction melted-vacuum arc remelted, centerless ground 2.54-cm (1.0-in) diameter bar supplied by Latrobe Steel Company. The heat numbers and chemical compositions of these alloys are presented in Table 1. The chemical analyses reported were performed at Marshall Space Flight Center by using Inductively Coupled Plasma (ICP) Emission Spectroscopy and LECO combustion [4].

SCC samples of AISI 9310 and M-50 NiL steels were fabricated to the dimensions shown in Figure 1 which are 0.635-cm (0.25-in) gauge diameter and 5.08-cm (2-in) overall length, with copper-plated threaded ends. These samples were carburized (see Appendices A and B), and the depth of carburization was determined through microhardness. (The case depth is defined in Reference 5 as the perpendicular distance from the carburized surface to the depth where the hardness is equivalent to Rockwell "C" 50.) Tensile specimens of both materials were cut, polished, and etched. Afterwards, Diamond Pyramid Hardness (DPH) readings were taken at several distances from the case surface and converted to Rockwell C hardness values.

Both materials were tested in two conditions, bare and plated with TDC to a thickness of 1.78×10^{-3} mm (70×10^{-6} in). The bare samples were received in sealed plastic bags and protected with a lubricant. All the samples were vapor degreased with perchloroethylene for 6 min and rinsed ultrasonically with Freon for 10 min. Several samples subjected to a tensile test broke prematurely in the threads due to notch sensitivity. M-50 NiL was more susceptible to this type of failure. Since no tensile data were obtained, published moduli of elasticity (1.97×10^5 MPa (28.5×10^6 psi) for carburized AISI 9310 and 2.03×10^5 MPa (29.5×10^6 psi) for carburized M-50 NiL) were used to determine the strain corresponding to the desired stress level. The use of these moduli was considered acceptable in view of the stress levels in this test being below the elastic limit.

Samples were stressed by using the stressing frames and device described in ASTM Standard G49 [6] and shown in Figures 2 and 3. The stressing device was developed to ensure axial loading with a minimum of torsion and bending of the specimen. The stressing frames used in this test were made of precipitation hardening stainless steel PH 13-8 Mo, which was in the annealed condition. The frames were later aged for 4 h at 538 °C (1,000 °F) to the H1000 condition. Once the round tensile specimen and frame parts were assembled together as shown in Figure 2, an extensometer was attached to the sample. The two side bars (wedges) were forced toward the center by means of the stressing device until the desired strain was reached. Upon completion of the loading procedure, a constant strain was maintained on the samples. Some notes on constant strain loaded specimens exposed to a corrosive environment are presented in Appendix C. By using this method, bare samples of carburized AISI 9310 and carburized M-50 NiL were stressed to 172, 345, and 517 MPa (25, 50, and 75 ksi). Samples plated with TDC were stressed to 517 MPa (75 ksi). The threads of the samples were protected with Conoco HD calcium grease No. 2 to prevent galvanic action or crevice corrosion between the stressing frames and the specimens. The sample gauge lengths were cleaned with acetone and the samples were placed in the humidity cabinet (Fig. 4) the same day they were stressed. The humidity cabinet was set to maintain 100-percent relative humidity at 38 °C (100 °F). Additional information on this cabinet is presented in Appendix D. Samples were placed in such a way that condensation from any one specimen did not drip onto another. The samples were tested in quadruplicate, except for those stressed to 172 MPa (25 ksi) which were tested in quintuplicate. The test duration was 1 year with daily workday inspections of the samples. In order to perform fracture analysis, samples that failed (Fig. 5) were cleaned with a warm 50-percent lactic, 50-percent phosphoric acid solution (by volume); scrubbed with a soft hair brush under running water; and cleaned ultrasonically with acetone and with alcohol. This cleaning procedure safely removed corrosion products from the fractured surfaces without attacking the base metal. The cleaned samples were dried and placed in a desiccator until metallography or SEM analysis was performed.

To determine the extent and type of corrosion attack, some samples that had not broken apart after a long exposure were wet grit blast cleaned and examined under magnification. Photographs were also taken. Rectangular coupons (1.02 cm (0.4 in) by 1.78 cm (0.7 in) by 2.54 cm (1.0 in)) of carburized AISI 9310 were tested bare and with TDC plating. One of the plated samples was scribed with a diamond prior to humidity exposure. Rods (0.95-cm (3/8-in) diameter by 7.62-cm (3-in) long) of the two alloys were tested as well. All the samples were cleaned with acetone and with alcohol prior to exposure. Photographs of these samples were taken periodically.

RESULTS AND DISCUSSION

The SCC results obtained in this program are presented in Table 2. A graphical representation of those results is shown in Figure 6. As seen in Table 2, bare samples of carburized AISI 9310 steel initially stressed to 172 MPa (25 ksi) did not fail in 1 year of exposure. Most of those AISI 9310 samples initially stressed to 345 and 517 MPa (50 and 75 ksi) failed during the first 6 months of exposure. Failures also occurred on the TDC plated samples of AISI 9310 which were initially stressed to 517 MPa (75 ksi). Several samples (bare and plated) showed cracks visible to the naked eye even though they did not completely fracture (Figs. 7 and 8). However, some samples were found cracked and failed eventually as indicated in Table 2. Cracked samples that did not completely fracture were also considered failures.

As for the M-50 NiL bare samples, those initially stressed to 345 MPa (50 ksi) or below did not fail in 1 year. However, a failure occurred at 517 MPa (75 ksi). TDC was ineffective in preventing failures on M-50 NiL. Two plated samples out of four failed, actually faster than the bare sample.

Both alloys were found susceptible to corrosion attack. Bare AISI 9310 tensile samples developed more rust and corrosion products than M-50 NiL, as seen in Figure 9. The extent of corrosion of AISI 9310 at different periods of time can be observed in Figure 10. After removal of corrosion products from the tensile samples, significant pitting was found as seen in Figure 11.

Photographs of TDC plated AISI 9310 and M-50 NiL samples are presented in Figures 8, 12, 13, and 14 (A, B, and C). Even though the plated tensile samples rusted less than the rest of the samples, it must be emphasized that this protection did not avoid cracks or failures. The plated rectangular and cylindrical samples started to rust early in the test and deteriorated significantly as seen in Figures 14A, 14B, and 14C.

The depth of carburization at Rc 50 (approximately) was found to be between 0.89 mm (0.035 in) and 1.02 mm (0.040 in) for the AISI 9310 samples and between 1.52 mm (0.060 in) and 1.78 mm (0.070 in) for M-50 NiL. This is illustrated by microhardness readings shown in Figures 15 to 17. A cross-sectional view of AISI 9310 steel showing typical microstructure is presented in Figure 18.

Each carburized AISI 9310 specimen (bare and TDC plated) that failed in the SCC test showed a circumferential crack between the case and the core. This is illustrated in Figures 16 and 19 to 24B. The difference in hardness between the case and the core on stressed specimens exposed to a highly humid enviroment over a period of time might have been a contributing factor for those cracks since no cracks were seen on the samples pulled in a tensile test (Fig. 25). Some of these fractures show stress corrosion features (Figs. 23B and 24B).

The M-50 NiL specimens (bare and plated) which failed in humidity showed intergranular cracking (Figs. 26A, 26B, 27A, and 27B). It is believed that pits on the surface could have contributed to these failures (by reducing the cross sectional area which increases the stress). The fracture surface of a specimen tensile tested to failure is shown in Figure 28 for comparison.

CONCLUSIONS AND RECOMMENDATIONS

The results of this program indicate that carburized AISI 9310 and M-50 NiL steels can be susceptible to stress corrosion in a humid environment. The maximum sustained tensile stresses (initially applied) that the specimens withstood without failing in 100-percent RH at 38 °C (100 °F) were 172 MPa (25 ksi) for carburized AISI 9310 and 345 MPa (50 Ksi) for carburized M-50 NiL.

Both alloys showed susceptibility to general corrosion, with AISI 9310 being more susceptible than M-50 NiL. Significant pitting was also observed on both alloys. Adequate corrosion protection of these steels is recommended if they are to be used in humid environments. Thin, dense chrome did not provide 100-percent corrosion protection for these steels (corrosion spots could be seen during the first week); however, it avoided intensive corrosion attack which was present on the bare specimens. Since AISI 9310 is contemplated to be used for bearings, other alternatives for corrosion protection should be evaluated in the same environment. The carburized AISI 9310 tensile samples that failed in this test exhibited circumferential cracks between the case and the core. It is suspected that the difference in hardness between the case and the core on stressed samples exposed to a highly humid environment might have been a contributing factor in the circumferential cracking.

The results of this test provide a basis for comparison between 440C and carburized AISI 9310 and M-50 NiL as regards to their SCC behavior.

APPENDIX A

Heat Treatment of AISI 9310 (MRC Bearings)

Carburization Cycle

1. Place material in furnace and heat treat to 927 °C (1,700 °F) and 1.0 Carbon Potential (CP).
2. Hold at 927 °C (1,700 °F) and 1.0 CP for 9 hours.
3. Drop furnace temperature to 816 °C (1,500 °F).
4. Hold at 816 °C (1,500 °F) for 30 minutes.
5. Quench in oil at 71 to 93 °C (160 to 200 °F) for 20 minutes.
6. Wash with water with soluble detergents at 71 to 93 °C (160 to 200 °F) for 15 minutes.
7. Temper at 593 °C (1,100 °F) for 2 hours.
8. Air cool.

Hardening Cycle Per MRC Specification HT113 (Batch Furnace)

1. Heat to 829 °C (1,525 °F) for 60 minutes.
2. Quench in oil for 20 minutes.
3. Wash in warm water.
4. Deep freeze at –79 °C (–110 °F) for 1 hour.
5. Temper at 163 °C (325 °F) for 2 hours.

APPENDIX B

Heat Treatment of M-50 NiL (MRC Bearings)

Carburization Cycle

1. Place material in furnace and heat treat to 954 °C (1,750 °F) (air only).
2. Once furnace reaches 954 °C (1,750 °F) hold 30 minutes (air only).
3. Purge with nitrogen, methanol, air, natural gas (0.50 Carbon Potential (CP)).
4. Introduce atmosphere with 0.50 CP at 954 °C (1,750 °F).
5. Time 30 hours from when atmosphere reaches 0.50 CP.
6. Turn off air.
7. Drop furnace temperature to 816 °C (1,500 °F).
8. Turn off methanol, natural gas (high flow nitrogen).
9. Cool to 538 °C (1,000 °F) (high flow nitrogen).
10. Hold at 538 °C (1,000 °F) for 30 minutes (high flow nitrogen).
11. Remove from furnace and air cool.
12. Do not quench.

Hardening Cycle Per MRC Specification HT018 (Salt Bath)

1. Preheat at 843 °C (1,550 °F) for 3.5 minutes.
2. High heat at 1,088 °C (1,990 °F) for 3.5 minutes.
3. Quench at 593 °C (1,100 °F) for 3.5 minutes.
4. Martemp at 177 °C (350 °F) for 3.5 minutes.
5. Reheat in salt at 593 °C (1,100 °F) for 60 minutes.
6. Martemp at 177 °C (350 °F) for 15 minutes.
7. Homogenize at 177 °C (350 °F) for 15 minutes.

8. A. Shut off heating elements and keep lid closed.
   B. Hold for 15 minutes, then open lid.

9. A. Cool to 38 °C (100 °F).
   B. Wash or sandblast.

10. Temper at 538 °C (1,000 °F) for 2 hours.

11. Deep freeze at –79 °C (–110 °F) for 1 hour.

12. Temper at 538 °C (1,000 °F) for 2 hours. Air cool.

13. Temper at 538 °C (1,000 °F) for 2 hours. Air cool.

14. Temper at 538 °C (1,000 °F) for 2 hours. Air cool.

APPENDIX C

Notes on Constant Strain Loaded Specimens (References 6 and 7)

It must be noticed that the initial stress on the constant strain loaded specimens may not necessarily be the same stress after a long exposure because reduction of the cross-section area could occur due to localized pitting corrosion which decreases the cross-sectional area and increases the stress. This condition may lead to mechanical fracture or SCC failure of a material at an unknown stress higher than the intended nominal test stress. On the other hand numerous small cracks developing in close proximity may cause relaxation of the stress. This suggests that results obtained early in the test may be more representative of SCC susceptibility than those obtained after a long time when using this method.

APPENDIX D

Description of Humidity Cabinet (Reference 8)

The humidity cabinet used for this test consists of two rectangular steel boxes, one within the other, and a cover. The inner shell is lined with vulcanized rubber which does not affect the corrosiveness of the media. An insulating material covers the outer steel shell. The peaked cover drains condensation away from the specimens. When closed, the cover rests in a water-filled trough that seals the chamber during tests. Heat for the chamber comes from strip heaters located in the air space between the cabinet shells. Dry and wet bulb thermometers are inserted in the cover to measure temperature. To obtain high humidity, compressed air is bubbled up through deionized water which is replaced periodically. The test cabinet attains a relative humidity of approximately 100 percent and remains at that state except for short periods of time when the test cabinet is opened.

REFERENCES

1. ASTM Standard G79-83, "Standard Practice for Evaluation of Metals Exposed to Carburization Environments," 1983.

2. Aerospace Material Specification AMS 6265G, "Steel Bars, Forgings, and Tubing, SAE 9310, Vacuum Consumable Electrode Remelted," issued June 30, 1960, revised July 1, 1989.

3. AMS 6278, "Steel Bars, Forgings, and Tubing, Premium Aircraft-Quality for Bearing Applications, Double Vacuum Melted," issued October 1, 1985.

4. Memo EH32 (91-45) dated February 7, 1991, from S.V. Caruso to J.W. Montano, Subject: Analysis of AISI 9310 and M-50 NiL Steel.

5. Industrial Tectonics, Inc., "Carburizing and Heat Treatment Specification of 9310 Steel," November 12, 1982.

6. ASTM Standard G49-85, "Standard Practice for Preparation and Use of Direct Tension Stress-Corrosion Test Specimens," 1985, pp. 4–5.

7. Ketcham, S.J.: "Stress Corrosion Testing Methods," Symposium on Stress Corrosion Testing, ASTM STP 425, ASTM, 1967, pp. 3–6.

8. Industrial Filter and Pump Manufacturing Co. Manual, 1987.

Table 1. Chemical Analyses of AISI 9310 and M-50 NiL Steels (Weight Percent).

	AISI 9310 (Heat No. 53415-2)			M-50 NiL (Heat No. E3841)		
	(MSFC)	AMS 6265G		(MSFC)	AMS 6278	
		Min	Max		Min	Max
C	0.1170	0.07	0.13	0.1267	0.11	0.15
Mn	0.35	0.40	0.70	0.17	0.15	0.35
Si	0.15	0.15	0.35	0.15	0.10	0.25
P	0.004	--	0.015	0.003	--	0.015
S	0.00215	--	0.015	0.0015	--	0.010
Cr	1.01	1.00	1.40	4.15	4.00	4.25
Ni	3.17	3.00	3.50	3.49	3.20	3.60
Mo	0.08	0.08	0.15	4.01	4.00	4.50
Cu	0.04	--	0.35	0.03	--	0.10
W	--			0.04	--	0.15
V	--			1.14	1.13	1.33
Co	--			0.08	--	0.25
Fe	Balance	Balance		Balance	Balance	

Table 2. Stress Corrosion Test Results of Carburized AISI 9310 and Carburized M-50 NiL Steels.

100% Relative Humidity at 38°C (100°F)

Alloy	Stress Level		Bare Samples		TDC-Coated Samples	
	MPa	KSI	Failure Ratio	Days to Failure	Failure Ratio	Days to Failure
Carburized	172	25	0/5		Not Tested	
AISI 9310	345	50	3/4	24, 181, 247	Not Tested	
	517	75	4/4	13, 34(a), 44, 94	3/4	16(b), 29(c), 55(d)
Carburized	172	25	0/5		Not Tested	
M-50 NiL	345	50	0/4		Not Tested	
	517	75	1/4	153	2/4	93, 119

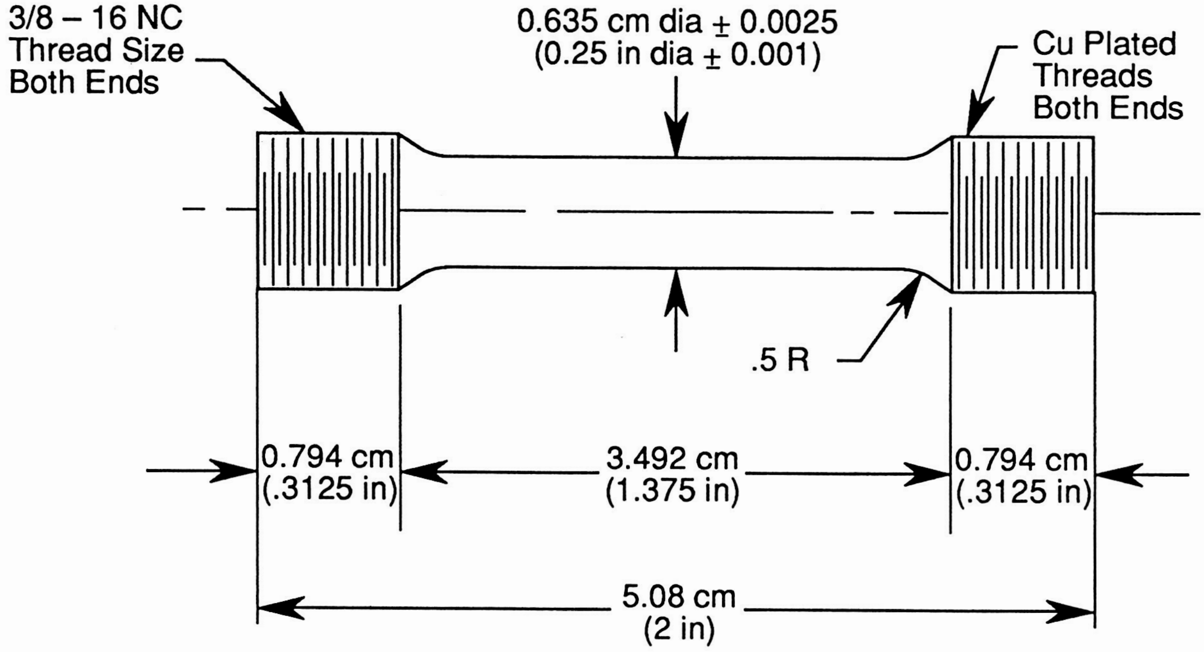
(a) A crack was seen in 34 days; sample did not break apart in 1 year of exposure.

(b) A crack was seen in 16 days; sample failed completely in 62 days.

(c) A crack was seen in 29 days; sample failed completely in 52 days.

(d) A crack was seen in 55 days; sample did not break apart after 1 year.

NOTE: The test duration was 1 year.



Notes: (1) No undercutting of radii permitted
(2) Taper gage length to center of specimen

Figure 1. Round Tensile Specimen.

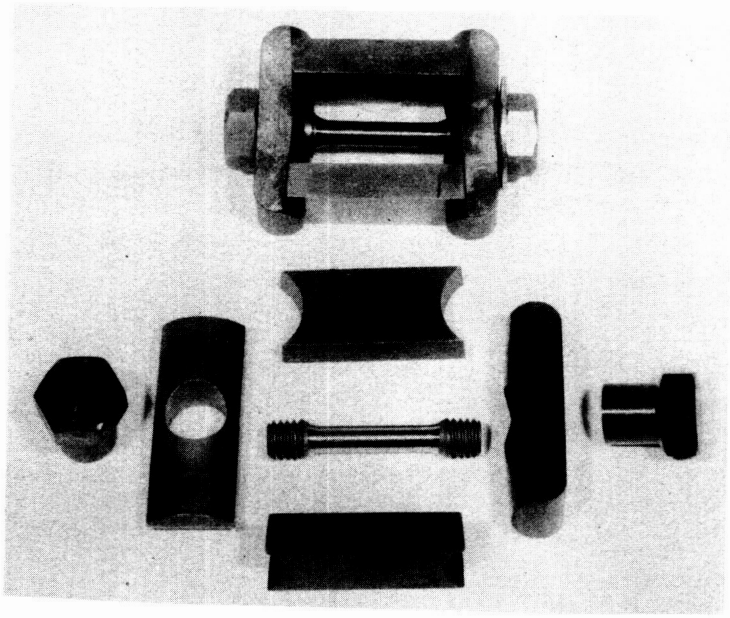


Figure 2. Stress Corrosion Frames Used to Stress Round Tensile Samples.

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BLACK AND WHITE PHOTOGRAPH

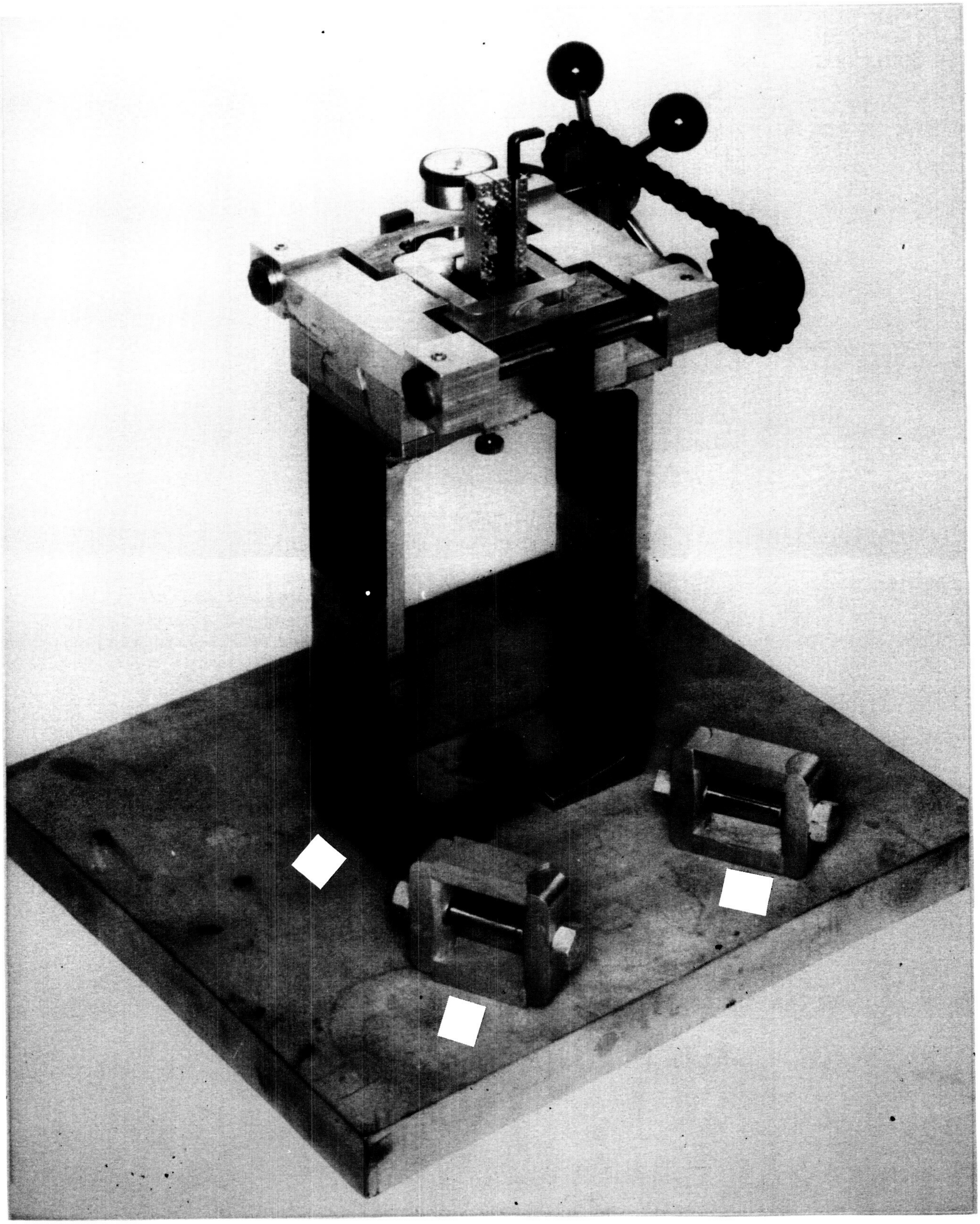


Figure 3. Device for Stressing Stress Corrosion Round Tensile Samples.

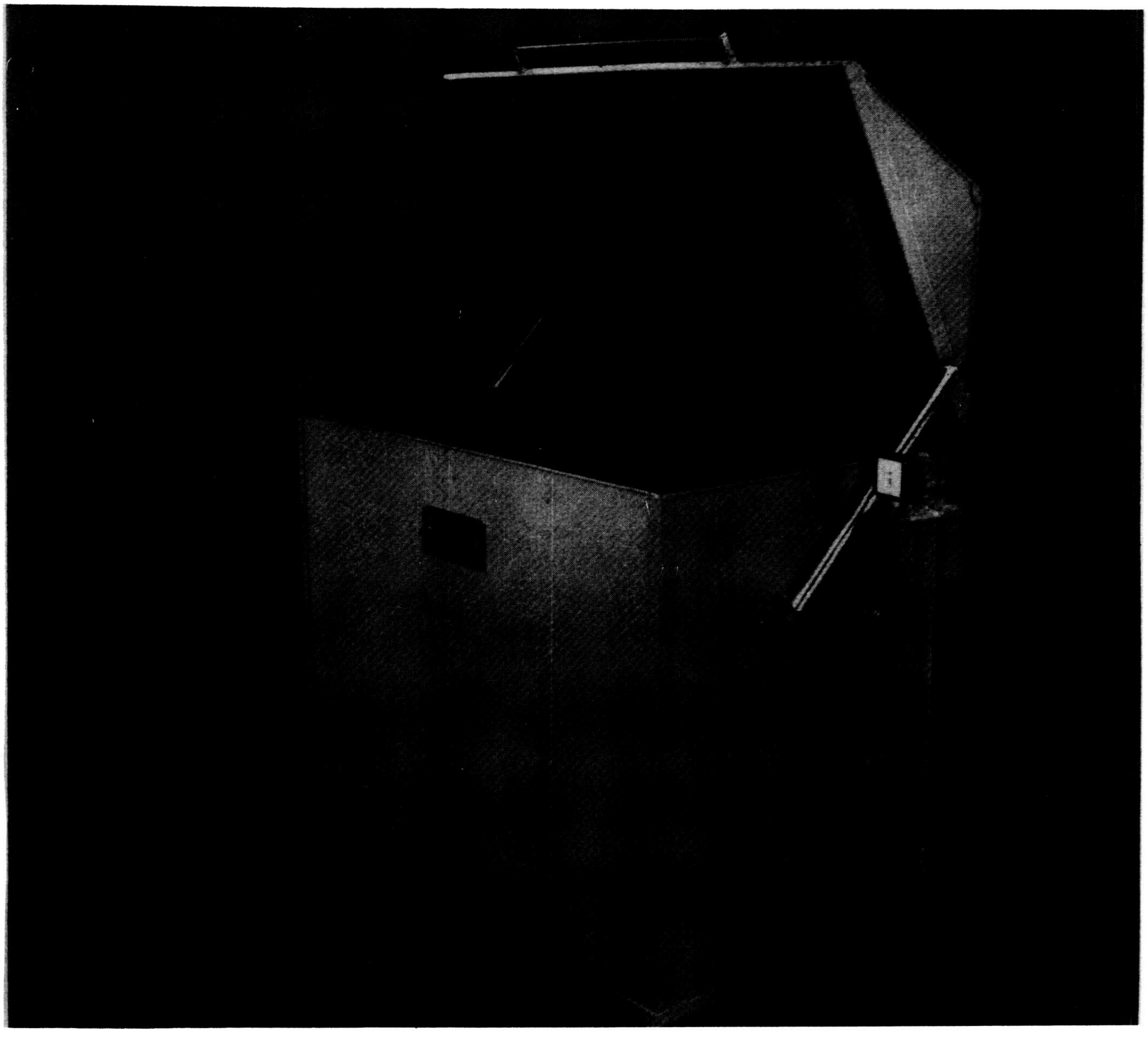


Figure 4. Test Cabinet for Environmental and Accelerated Corrosion Tests. Maintains 100-Percent Relative Humidity (RH) at 38 °C (100 °F).

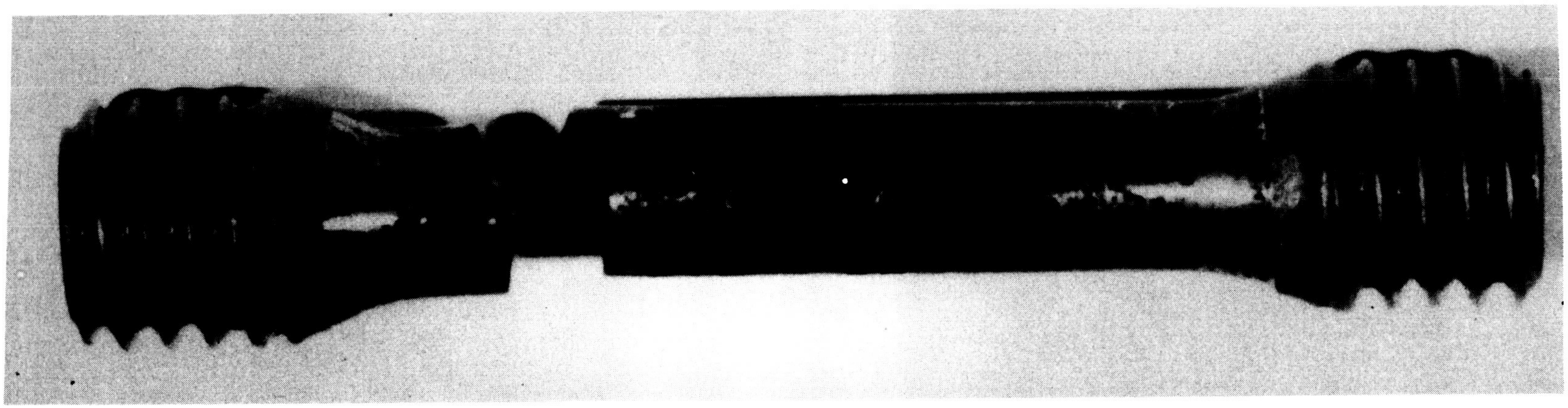
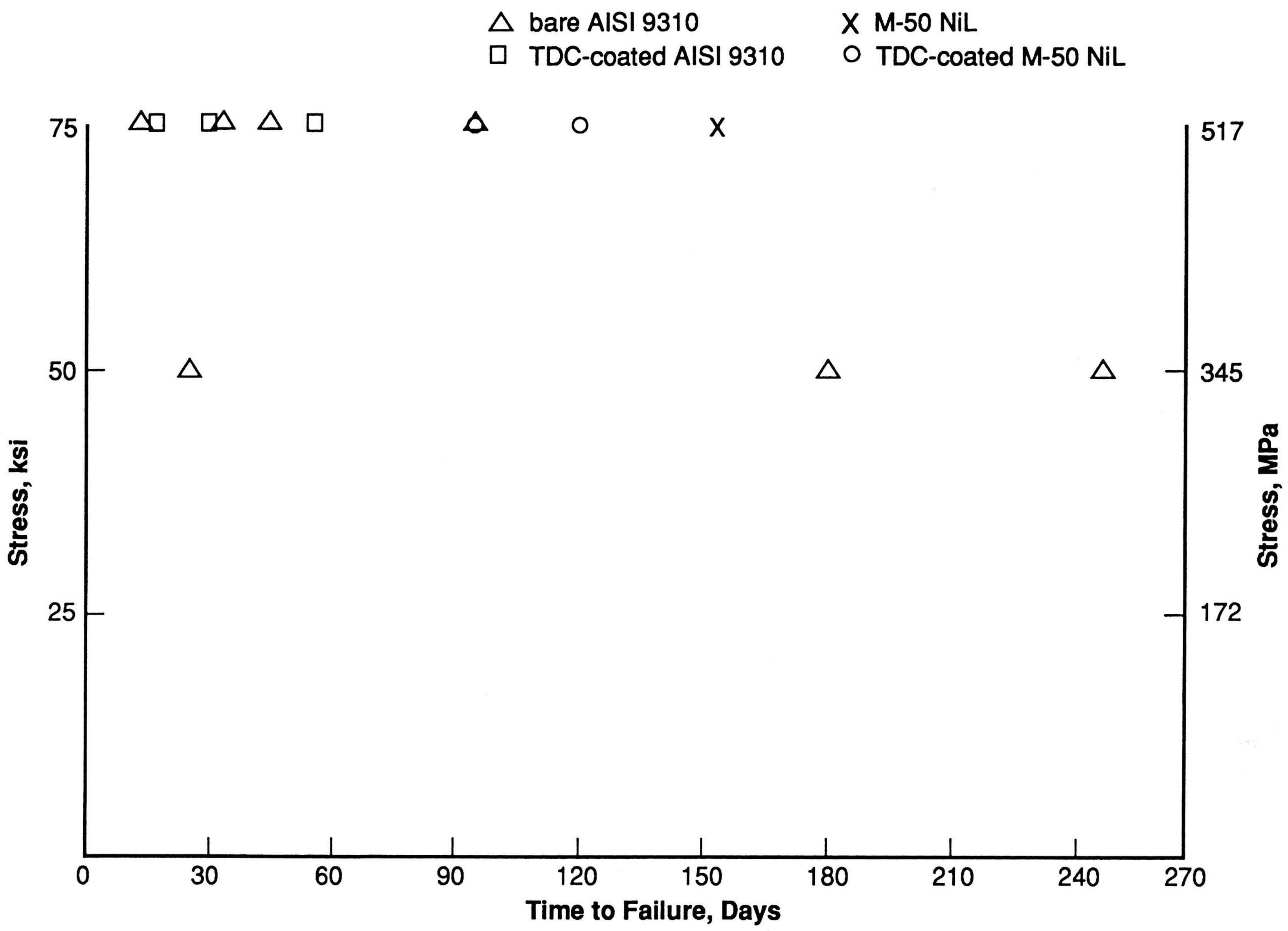
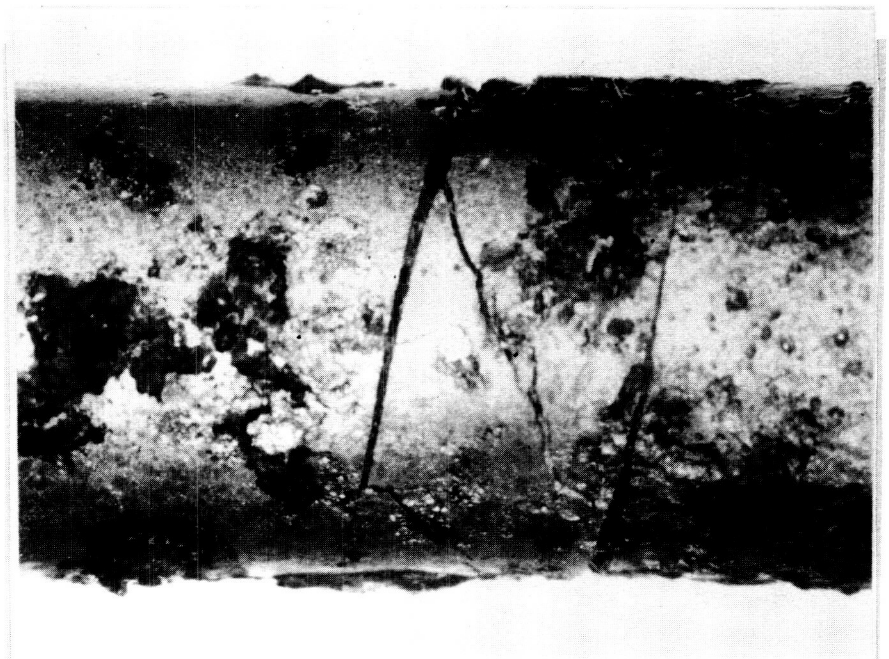


Figure 5. Carburized AISI 9310 Steel SCC Round Tensile Sample Failed in 13 Days. Initial Stress Applied was 517 MPa (75 ksi). 4X Magnification.



Note: TDC-Coated Samples Were Tested at 517 MPa (75 ksi) Stress.

Figure 6. Stress Versus Time to Failure for Carburized AISI 9310 and Carburized M-50 NiL Steels, Bare and Coated With Thin, Dense Chrome. Test Environment Was 100 Percent RH at 38 °C (100 °F).



(A)

(B)

Figure 7. Carburized AISI 9310 Steel Tensile Specimen Showing Corrosion Attack and Cracking After 351 Days in Humidity Cabinet (Initial Cracking in 34 Days Exposure). 10X Magnification.

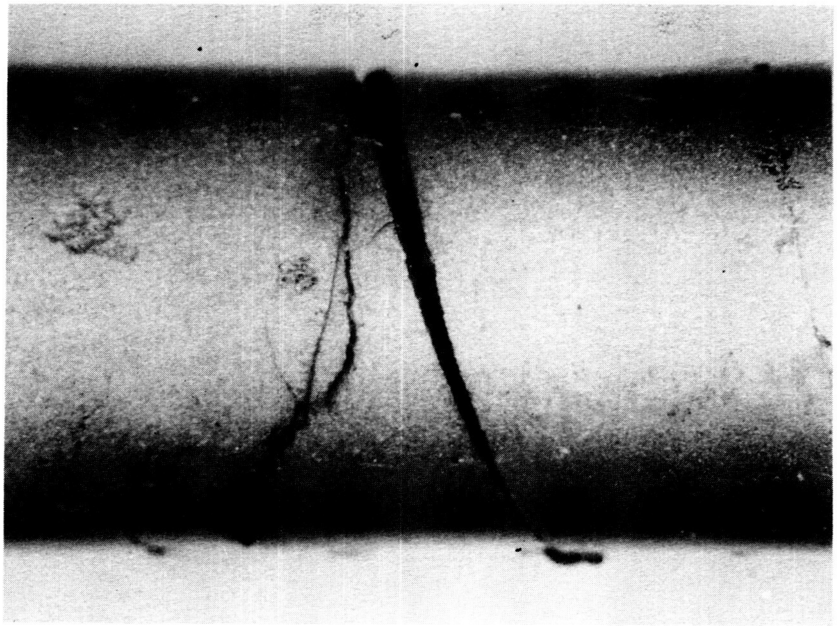


Figure 8. Carburized AISI 9310 Steel Tensile Specimen Plated With Thin, Dense Chrome Showing Multiple Cracking After 309 Days Exposure to Humidity (Initial Cracking in 55 Days). 10X Magnification.

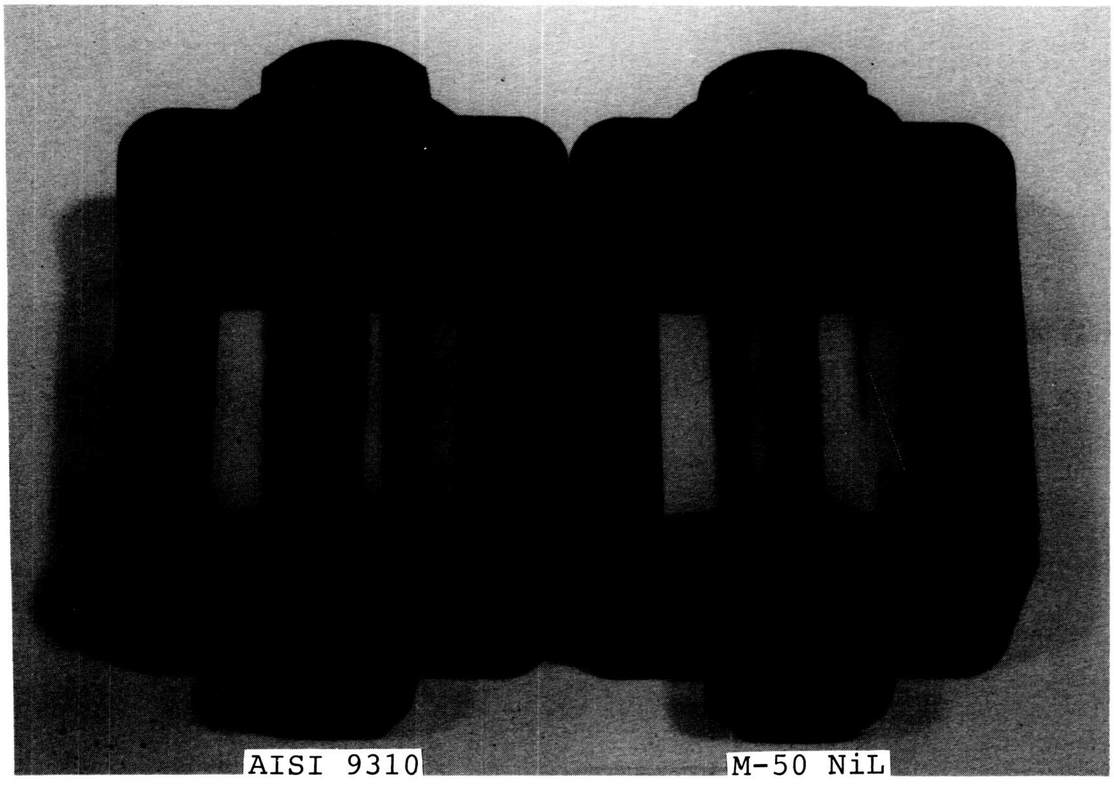


Figure 9. Carburized AISI 9310 and Carburized M-50 NiL SCC Samples Showing the Extent of Corrosion After 220 Days in Test.

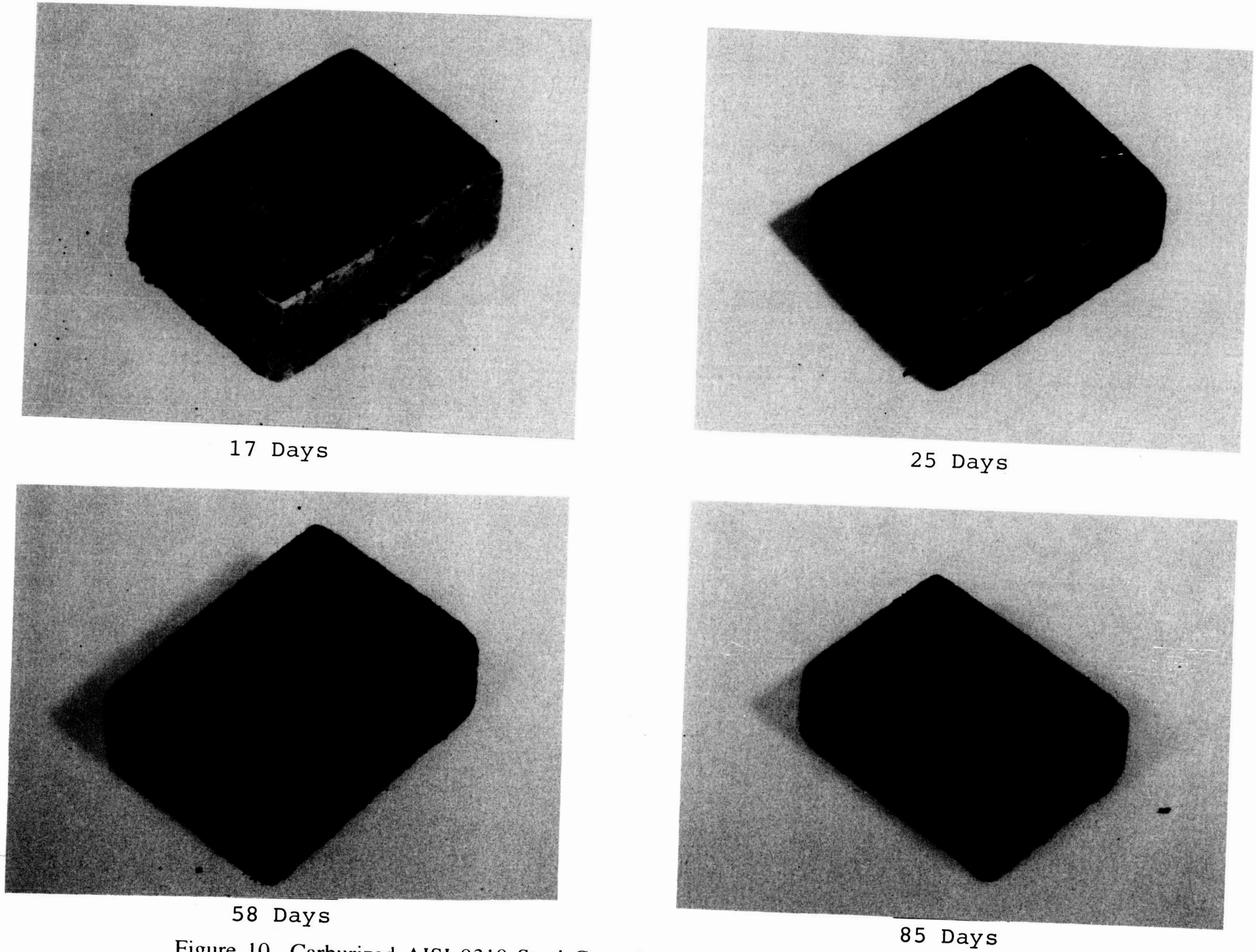
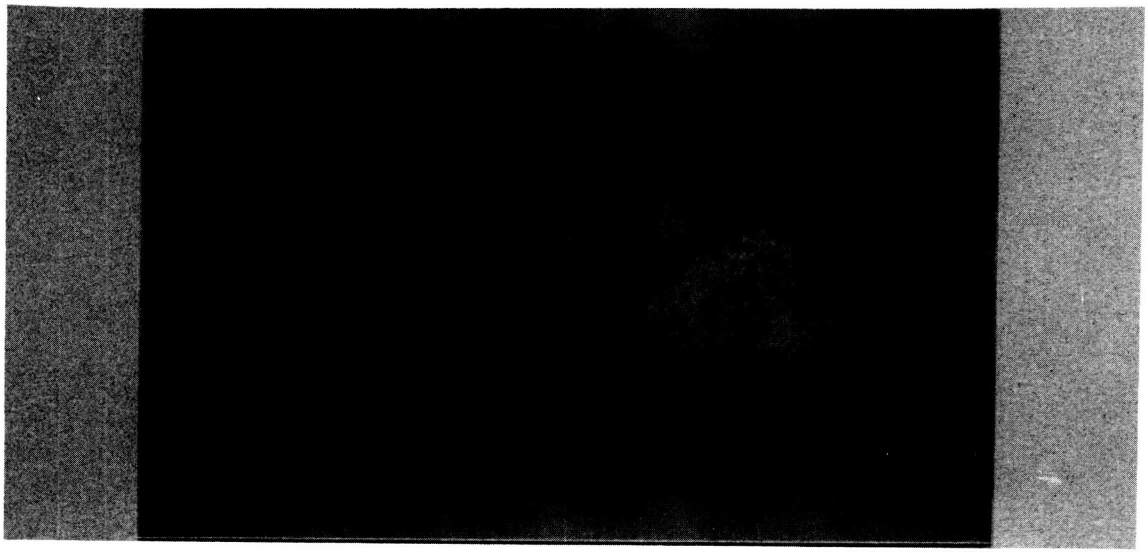


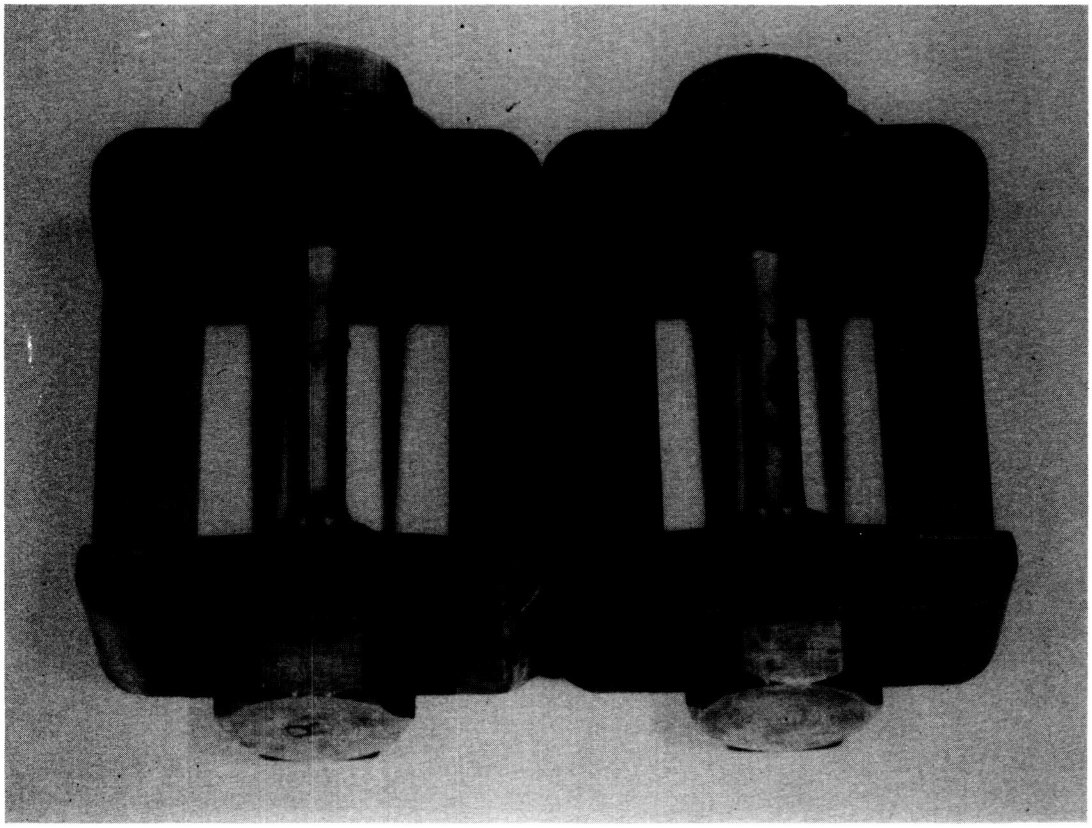
Figure 10. Carburized AISI 9310 Steel Corrosion Samples at Different Times of Exposure to Humidity Environment.



(A) Carburized AISI 9310; 172 MPa (25 ksi) Stress 9X Mag.

(B) Carburized M-50 NiL; 517 MPa (75 ksi) Stress 10X Mag.

Figure 11. Tensile Specimens of Carburized AISI 9310 and M-50 NiL Steels Showing Extensive Pitting After 1 Year Exposure to Humidity.



AISI 9310 Steel
178 Days

M-50 NiL
116 Days

Figure 12. Thin, Dense Chrome Plated Tensile Specimens Exposed to Humidity Environment.

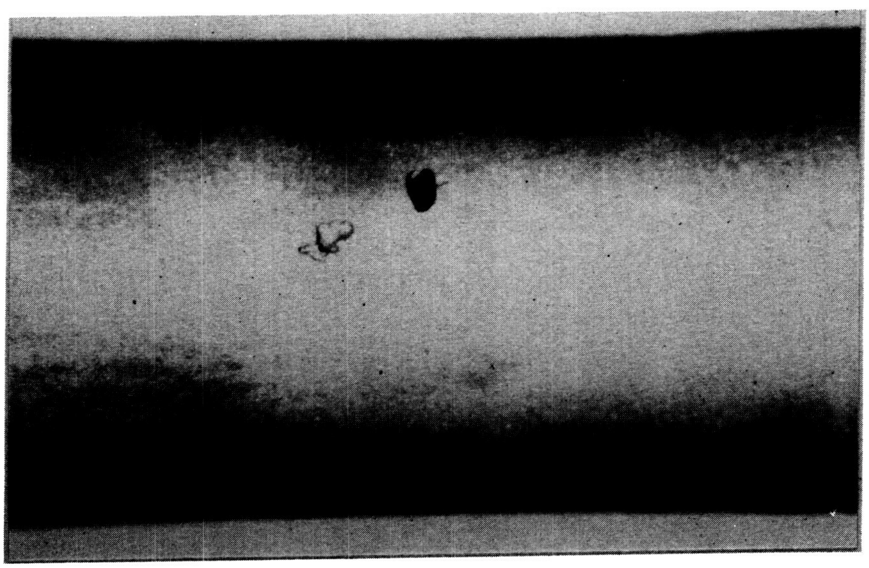
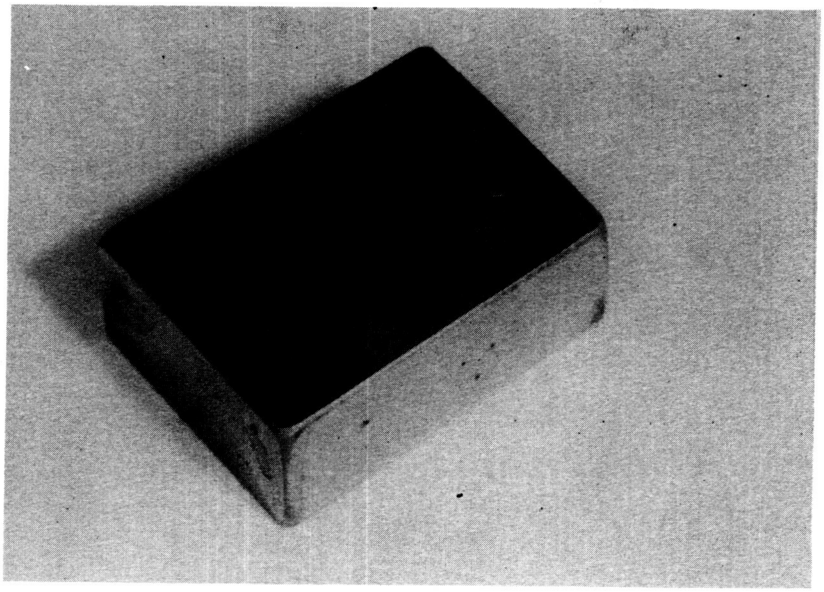
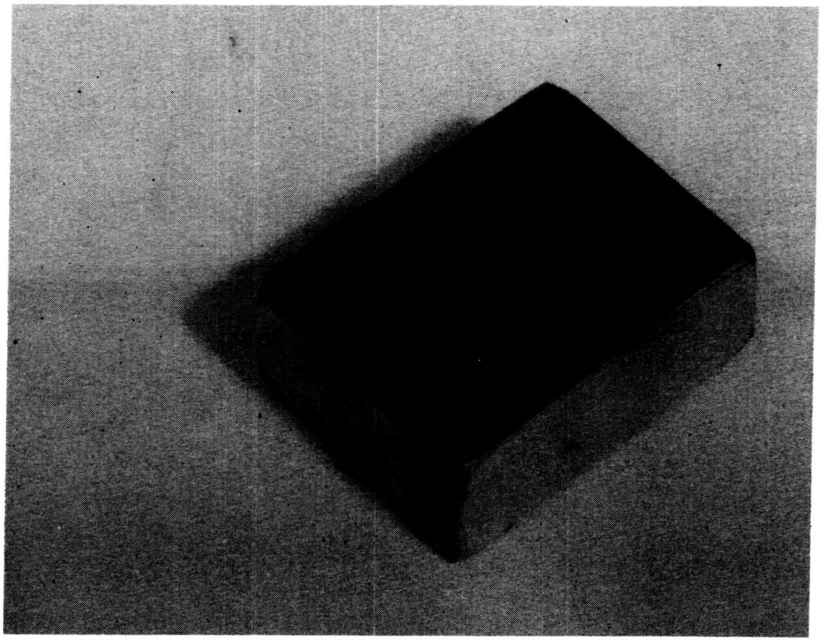


Figure 13. Carburized M-50 NiL Steel Tensile Specimen Plated With Thin, Dense Chrome Showing Pitting After 247 Days Exposure to Humidity Environments and 517 MPa (75 ksi) Stress. 10X Magnification.

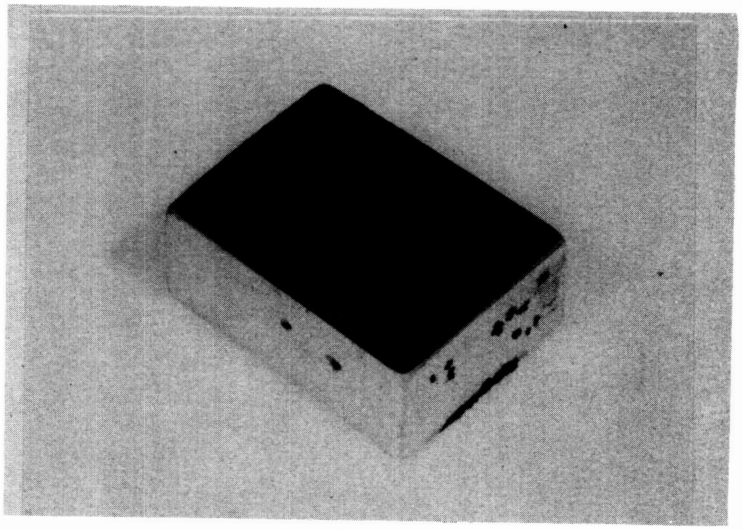


5 Days

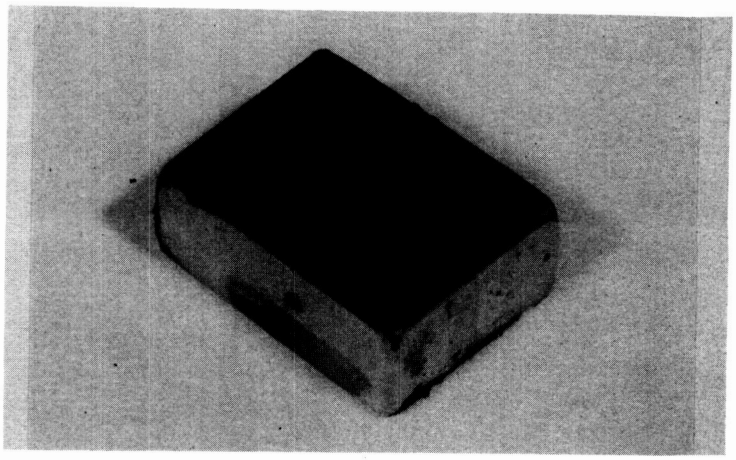


5 Days; Scribed With a Diamond

Figure 14A. Carburized AISI 9310 Steel Samples Plated With Thin, Dense Chrome and Exposed to Humidity.



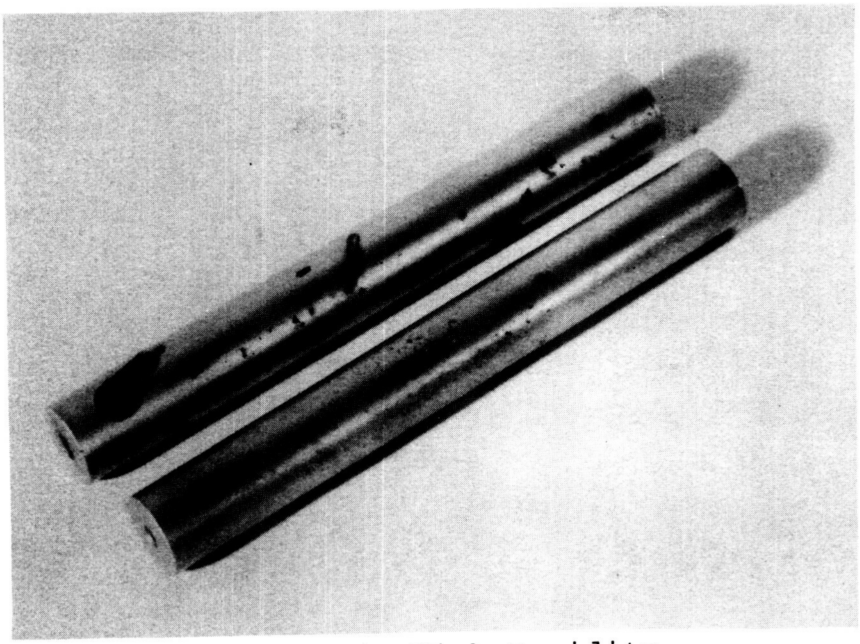
32 Days



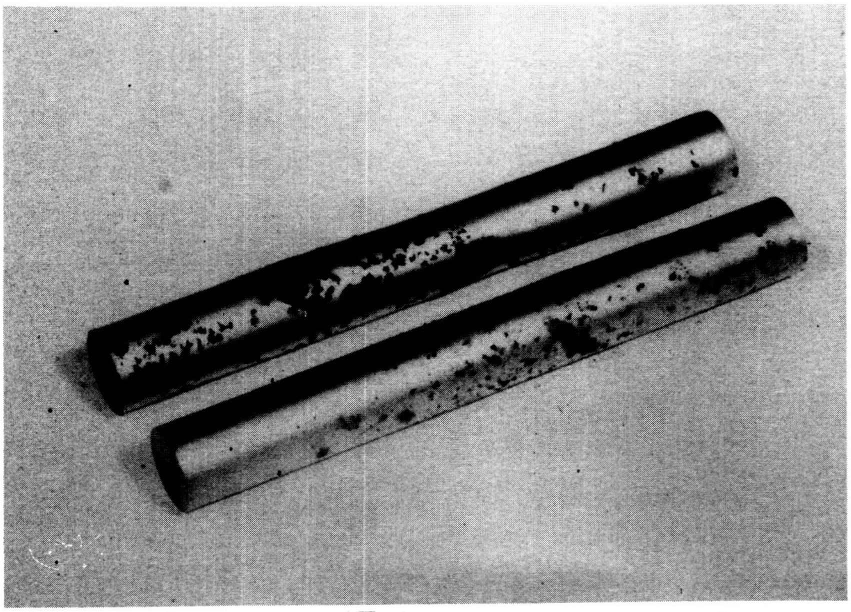
32 Days - Scribed With a Diamond

109 Days

Figure 14B. Carburized AISI 9310 Steel Corrosion Samples Plated With Thin, Dense Chrome and Exposed to Humidity.

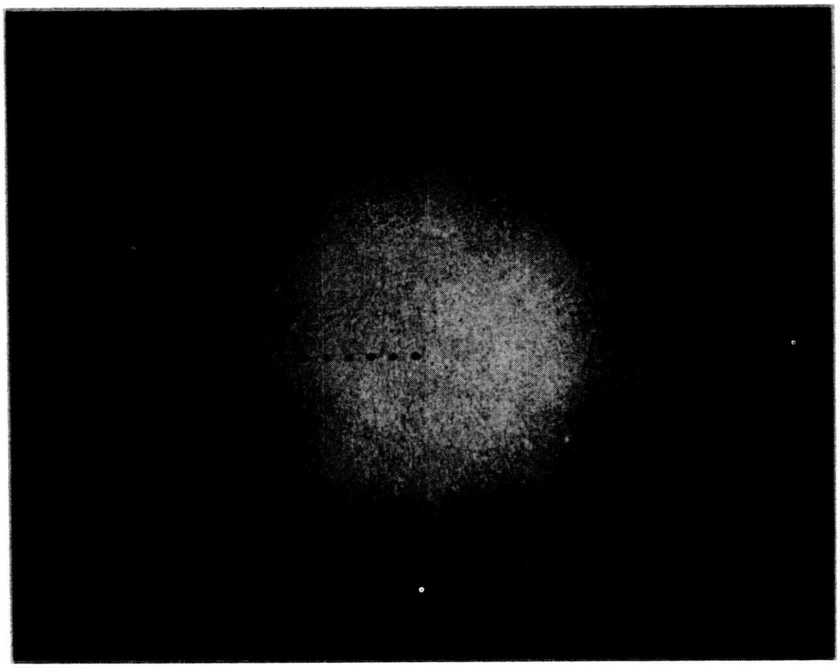


9 Days in High Humidity



36 Days in High Humidity

Figure 14C. Rods of Carburized AISI 9310 (Left) and Carburized M-50 NiL (Right) Steels Plated With Thin, Dense Chrome and Exposed to High Humidity.

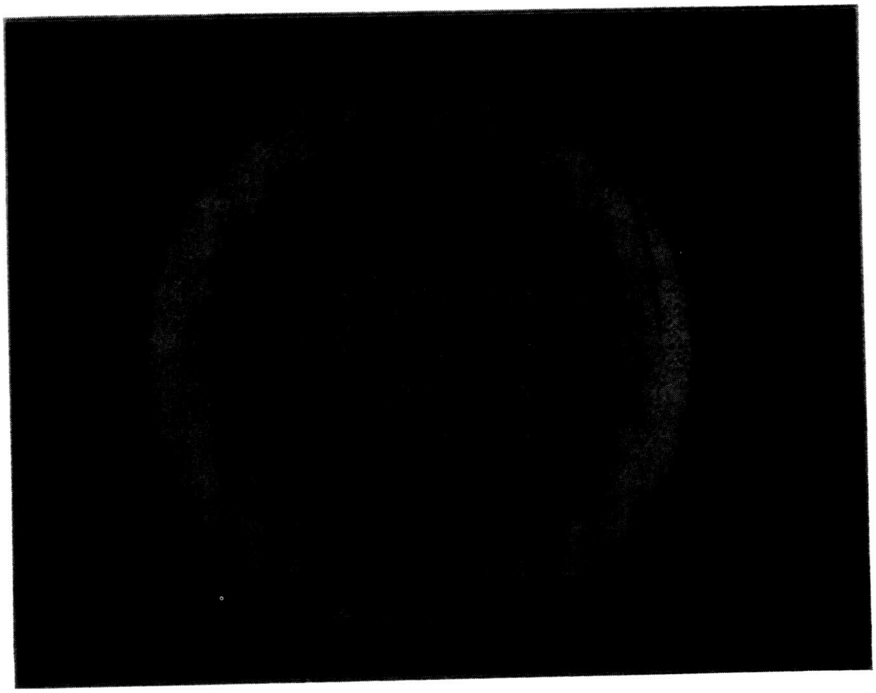


Nital Etch 12X Mag.

Microhardness Converted From DPH Readings

Distance from Surface MM	Distance from Surface IN	Rockwell C Hardness
0.254	0.010	62
0.508	0.020	60
0.762	0.030	56
1.016	0.040	51
1.270	0.050	47
1.524	0.060	44
1.778	0.070	41
2.032	0.080	41
2.286	0.090	40
2.540	0.100	41
2.794	0.110	41
3.048	0.120	40

Figure 15. Cross Section of Carburized AISI 9310 Steel Tensile Specimen Showing Depth of Carburization.

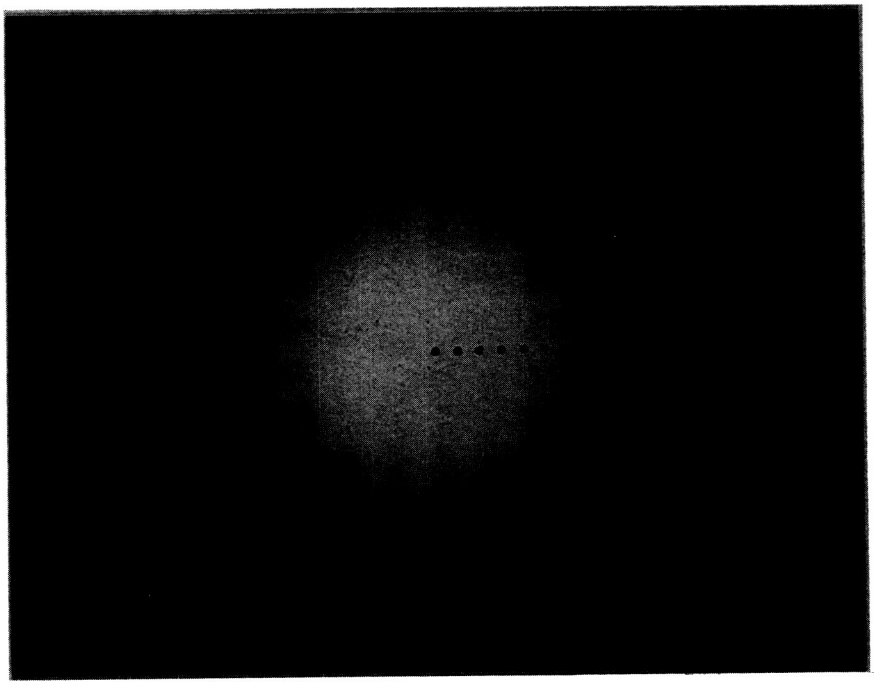


Nital Etch 12X Mag.

Microhardness Converted From DPH Readings

Distance from Surface		Rockwell C Hardness
MM	IN	
0.127	0.005	63
0.254	0.010	61
0.381	0.015	59
0.508	0.020	58
0.635	0.025	56
0.762	0.030	54
0.889	0.035	52
1.016	0.040	49
1.143	0.045	46
1.270	0.050	44
1.397	0.055	42

Figure 16. Cross Section Showing Cracking and Microhardness Readings on a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 94 Days of Humidity.



Nital Etch 12X Mag.

Microhardness Converted From DPH Readings

Distance from Surface MM	IN	Rockwell C Hardness
0	0	62
0.254	0.010	62
0.508	0.020	60
0.762	0.030	60
1.016	0.040	59
1.270	0.050	57
1.524	0.060	53
1.778	0.070	49
2.032	0.080	46
2.286	0.090	44
2.540	0.100	42
2.794	0.110	41
3.048	0.120	41

Figure 17. Cross Section Showing Microhardness Readings on an M-50 NiL Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 93 Days of Humidity.

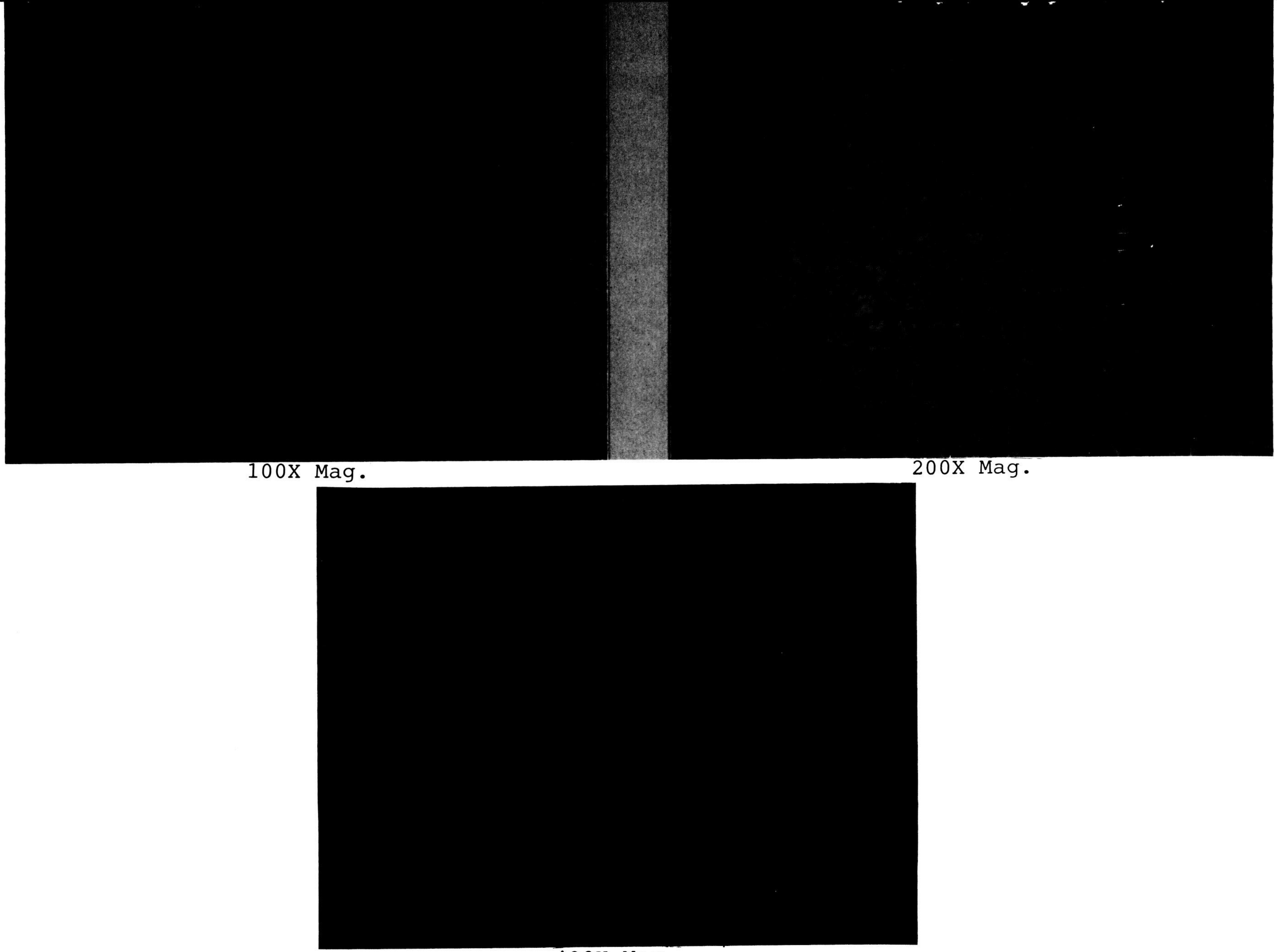
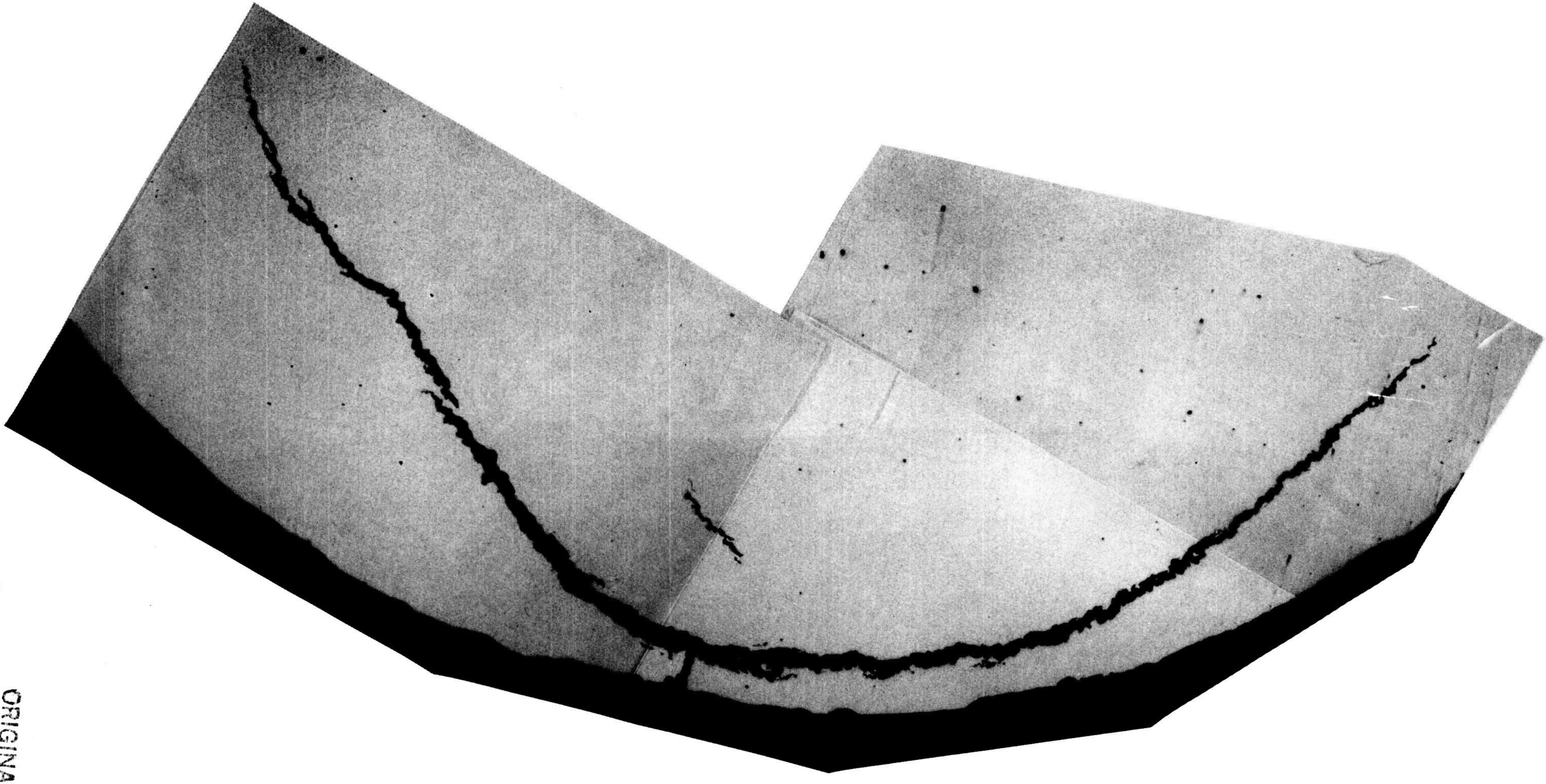


Figure 18. Cross Sectional Views of AISI 9310 Steel Showing Typical Microstructure. Etchant: Nital.



50X Mag.

Figure 19. Cross Section Showing Cracking of a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 94 Days of Humidity.

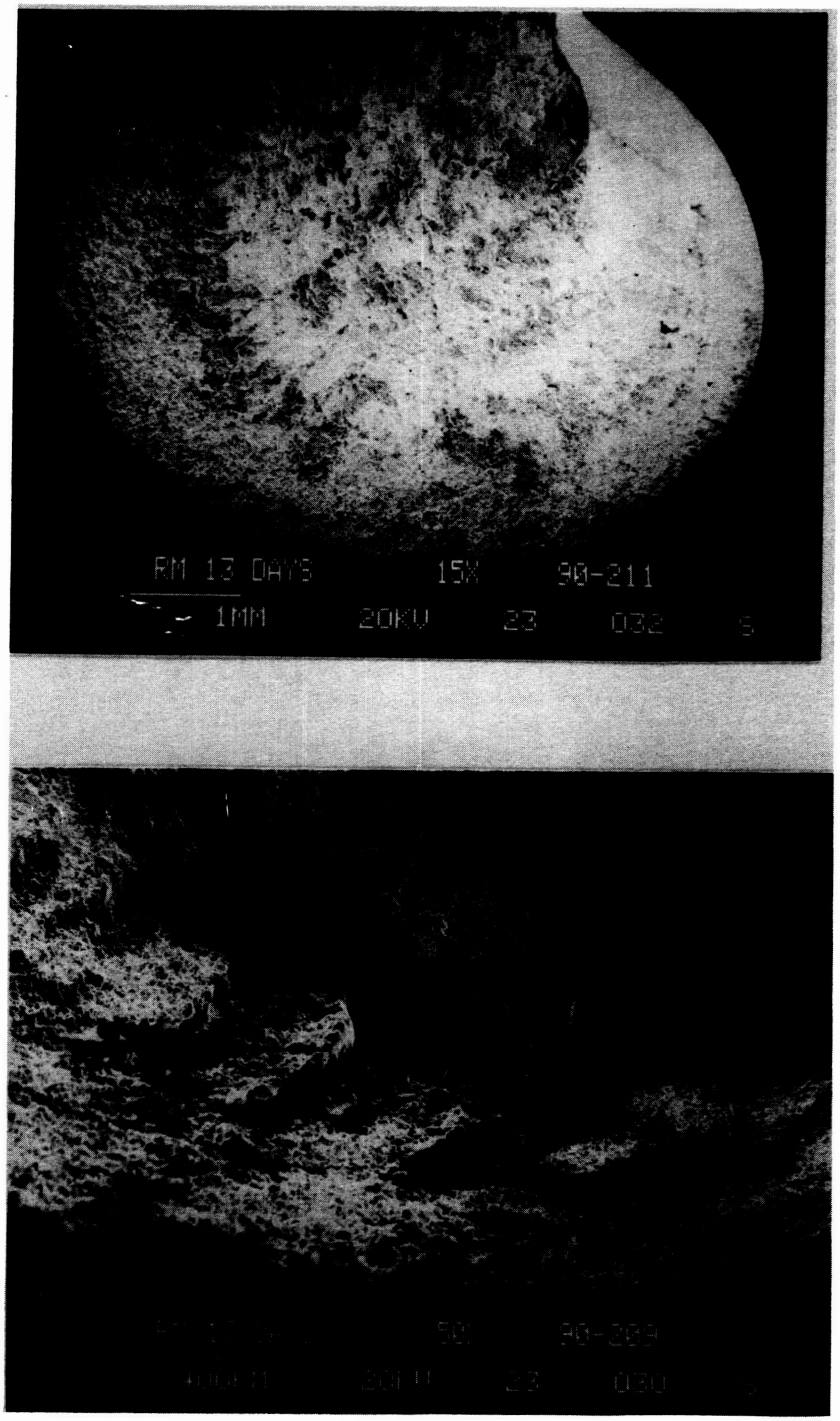


Figure 20A. SEM Views Showing Fractured Surface of a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 13 Days of Humidity.

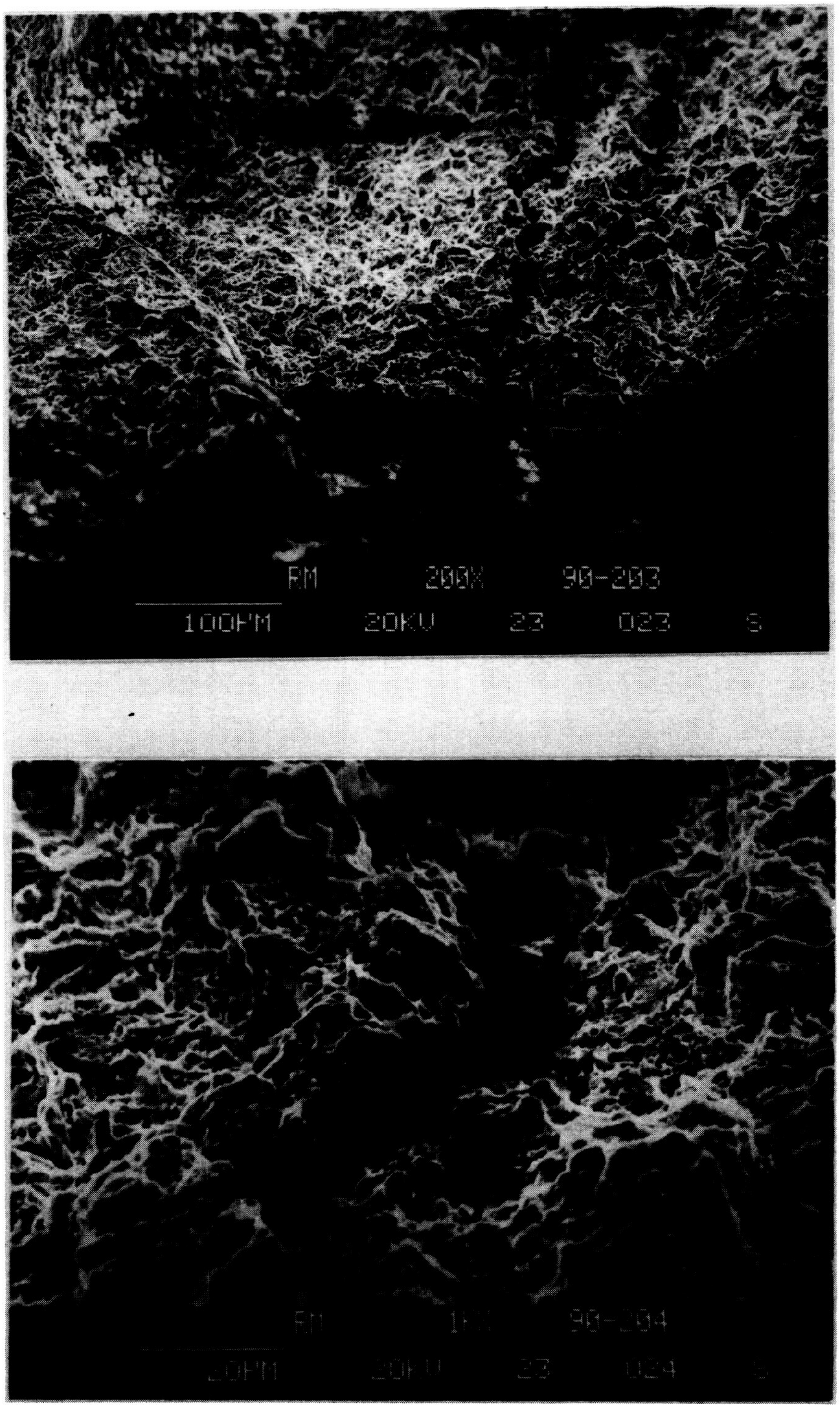
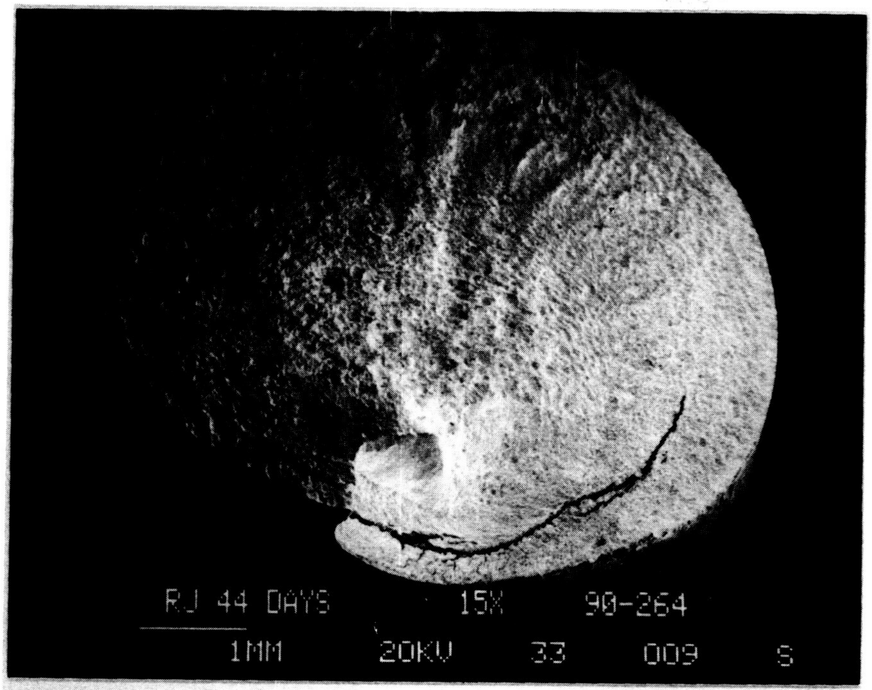


Figure 20B. SEM Views Showing Cracking of the Fractured Surface of a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 13 Days of Humidity.



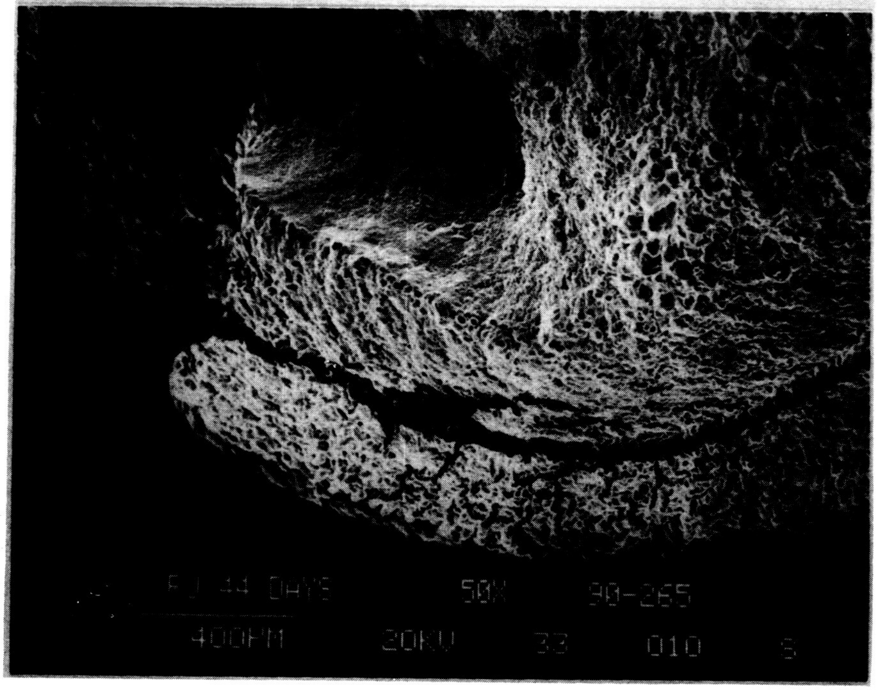
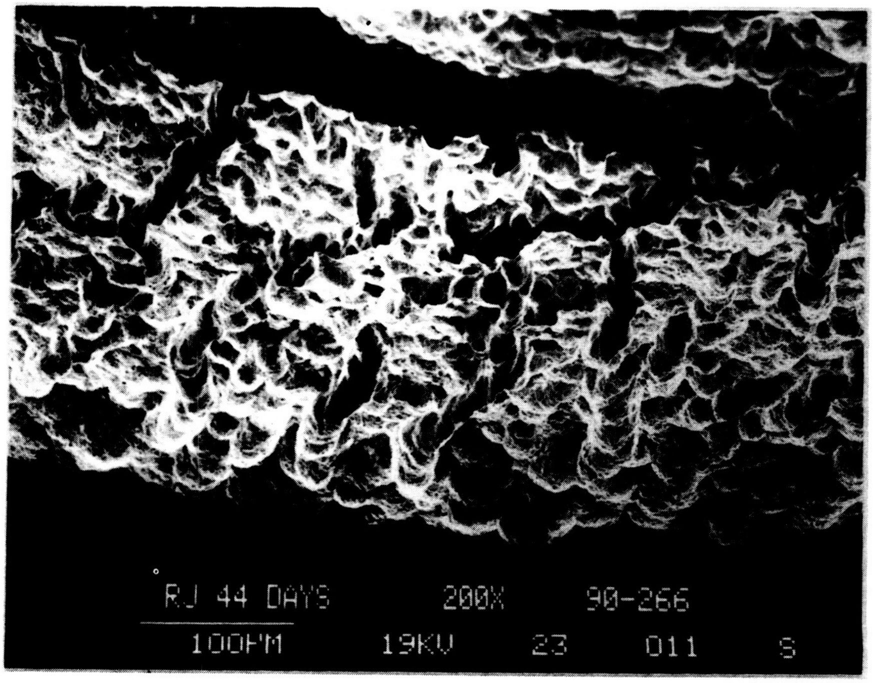


Figure 21A. SEM Views Showing Cracking of the Fractured Surface of a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 44 Days of Humidity.



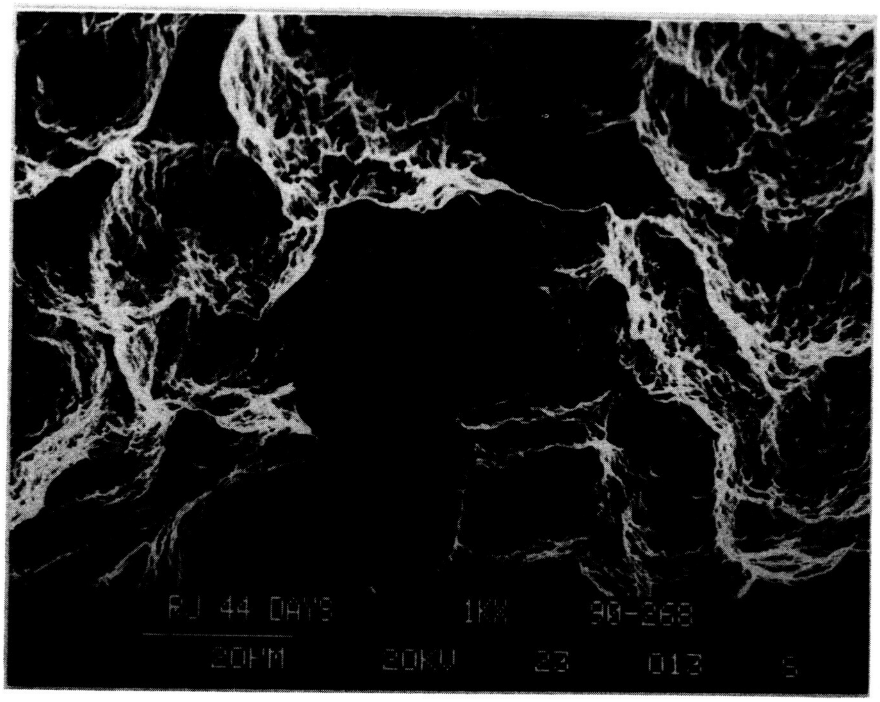


Figure 21B. SEM Views Showing Depth of Cracking of a Carburized AISI 9310 Steel Specimen Stressed to 517 MPa (75 ksi) and Exposed to 44 Days of Humidity.

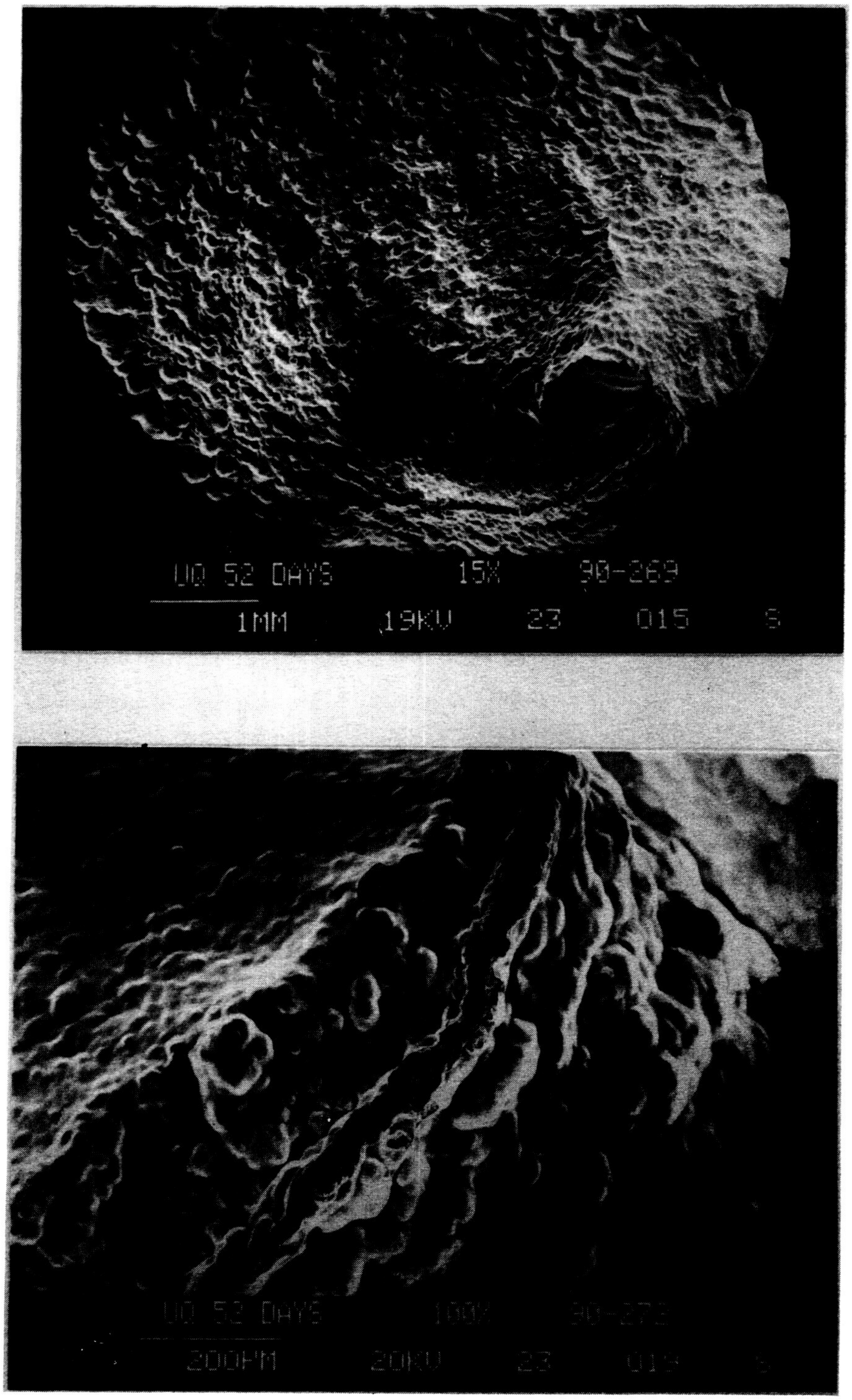


Figure 22A. SEM Views Showing Cracking of the Fractured Surface of a Carburized AISI 9310 Steel Specimen Plated With Thin, Dense Chrome, Stressed to 517 MPa (75 ksi), and Exposed to 52 Days of Humidity.

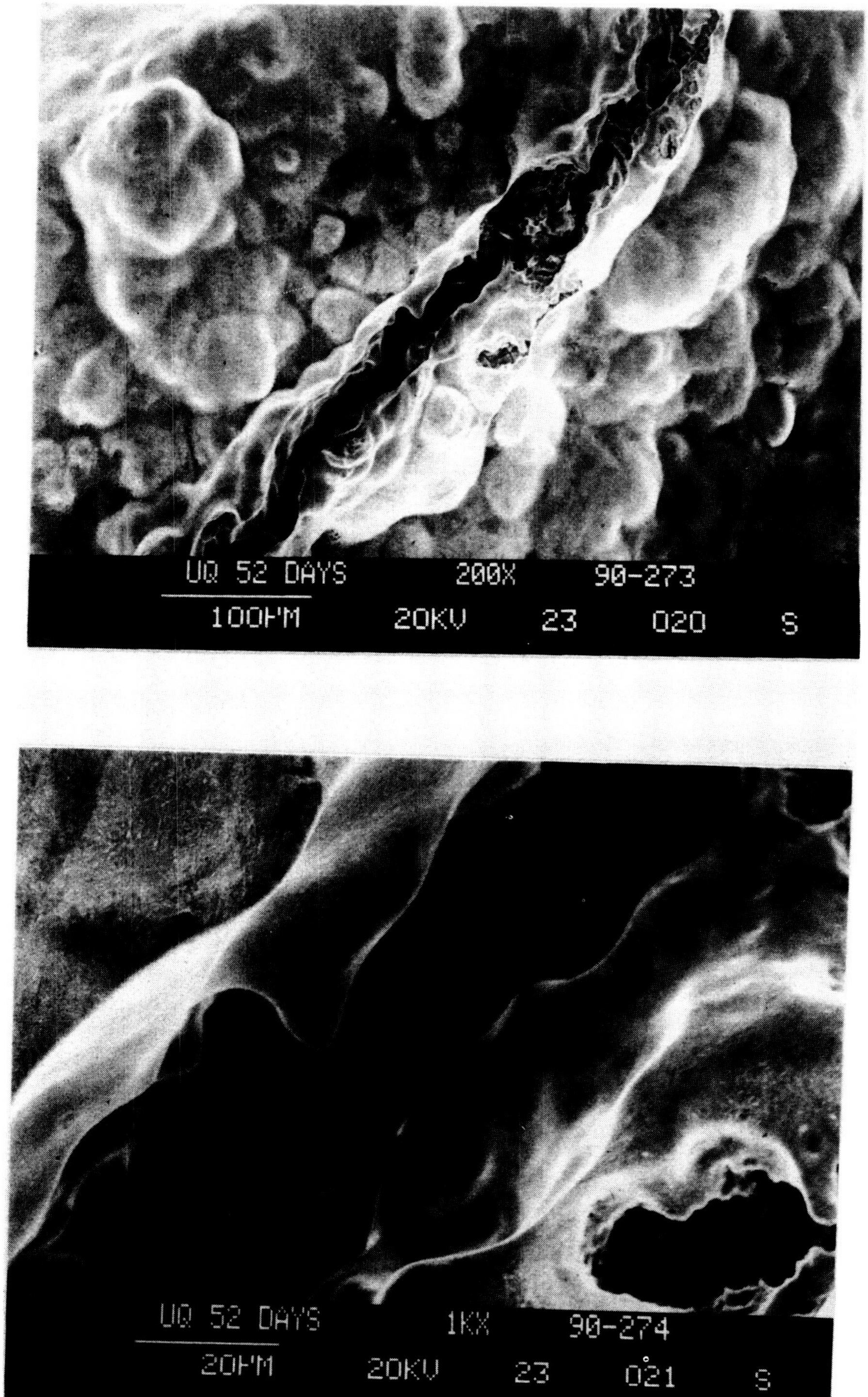
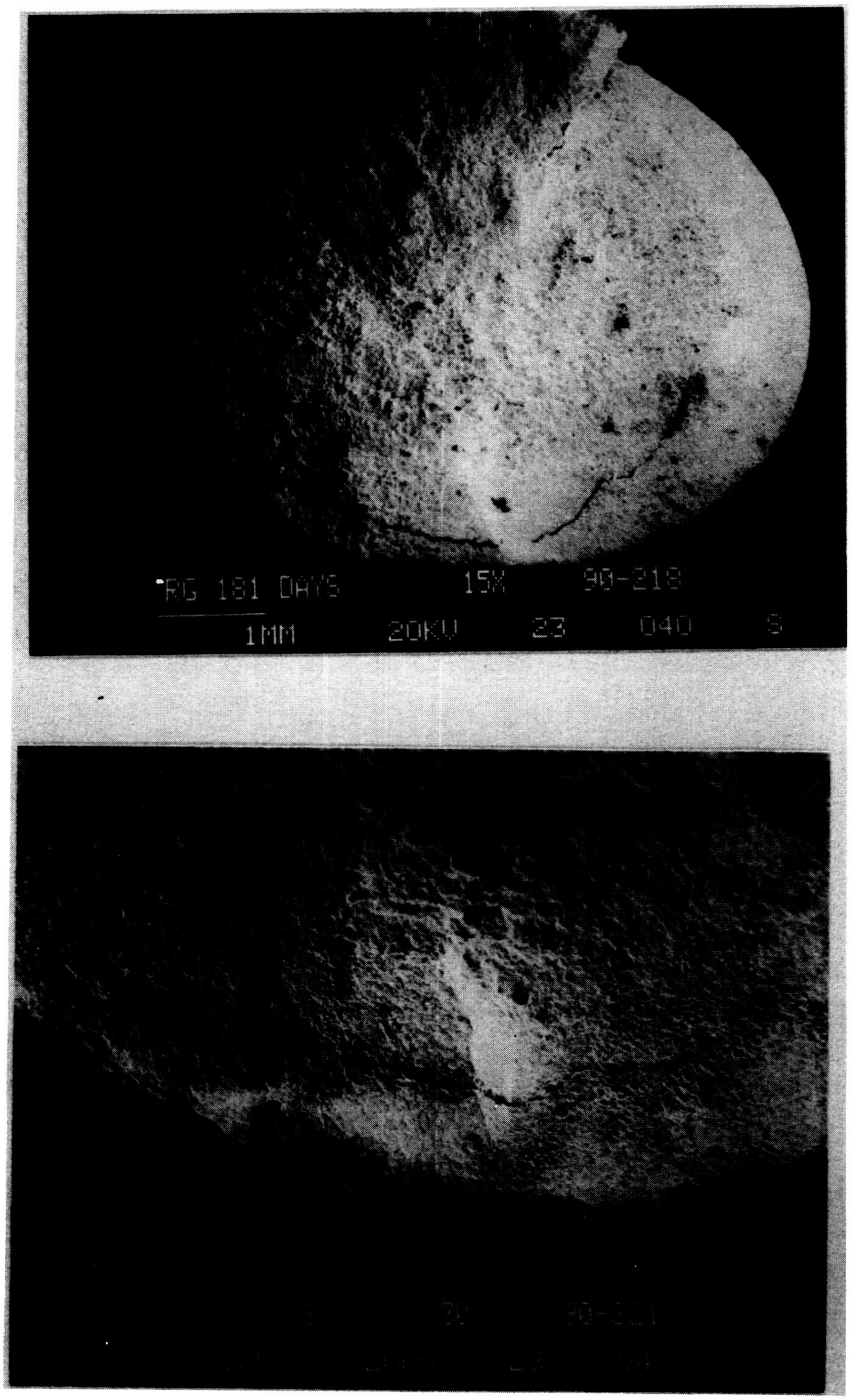
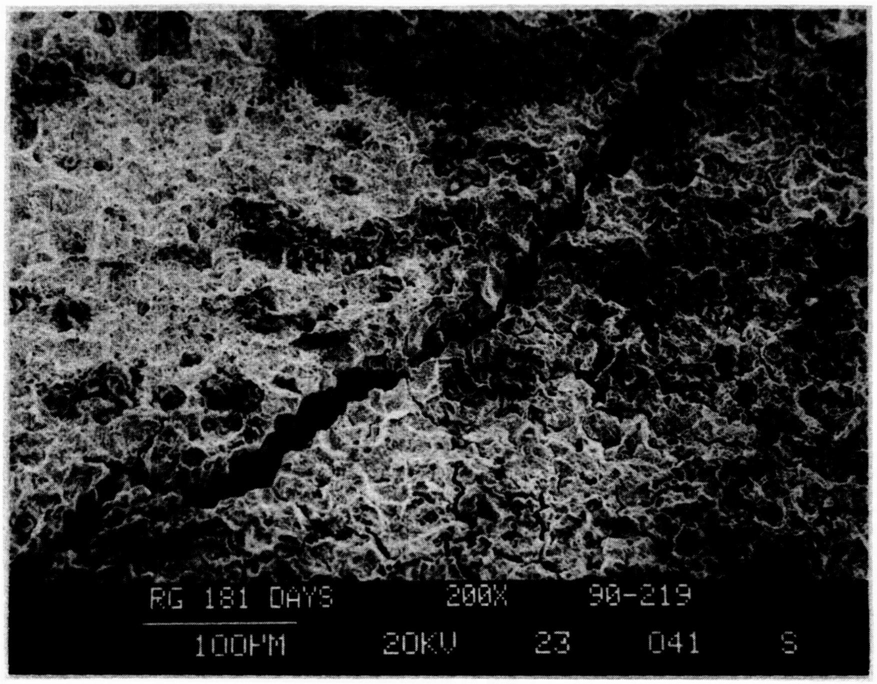


Figure 22B. SEM Views Showing Depth of Cracking of a Carburized AISI 9310 Steel Specimen Plated With Thin, Dense Chrome, Stressed to 517 MPa (75 ksi), and Exposed to 52 Days of Humidity.



Figue 23A. SEM Views Showing Cracking of the Fractured Surface of a Carburized AISI 9310 Steel Specimen Stressed to 345 MPa (50 ksi) and Exposed to 181 Days of Humidity.



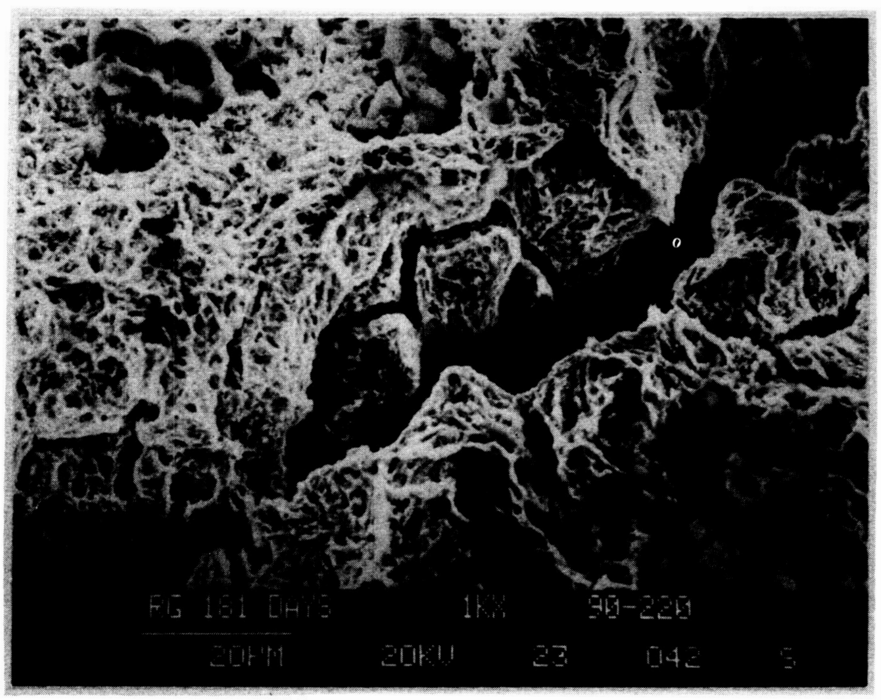


Figure 23B. SEM Views Showing Blocky Intergranular Cracking of a Carburized AISI 9310 Steel Specimen Stressed to 345 MPa (50 ksi) and Exposed to 181 Days of Humidity.

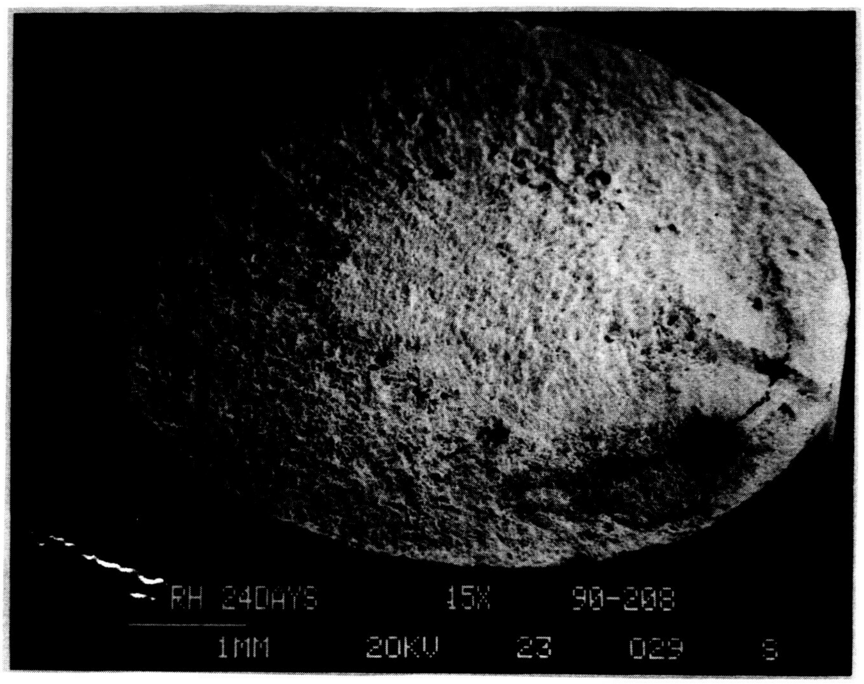
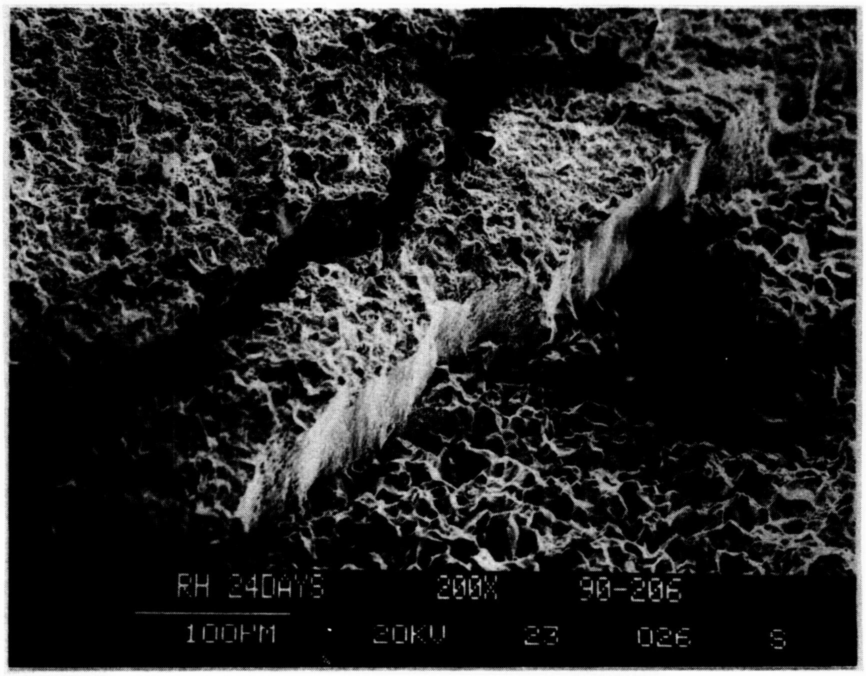


Figure 24A. SEM Views Showing Cracking of the Fractured Surface of a Carburized AISI 9310 Steel Specimen Stressed to 345 MPa (50 ksi) and Exposed to 24 Days of Humidity.



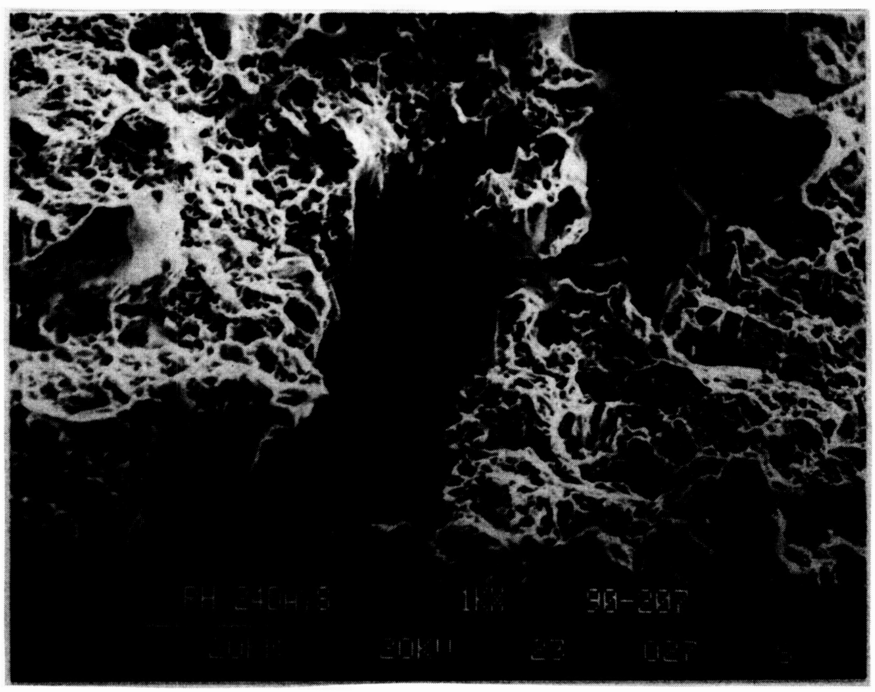
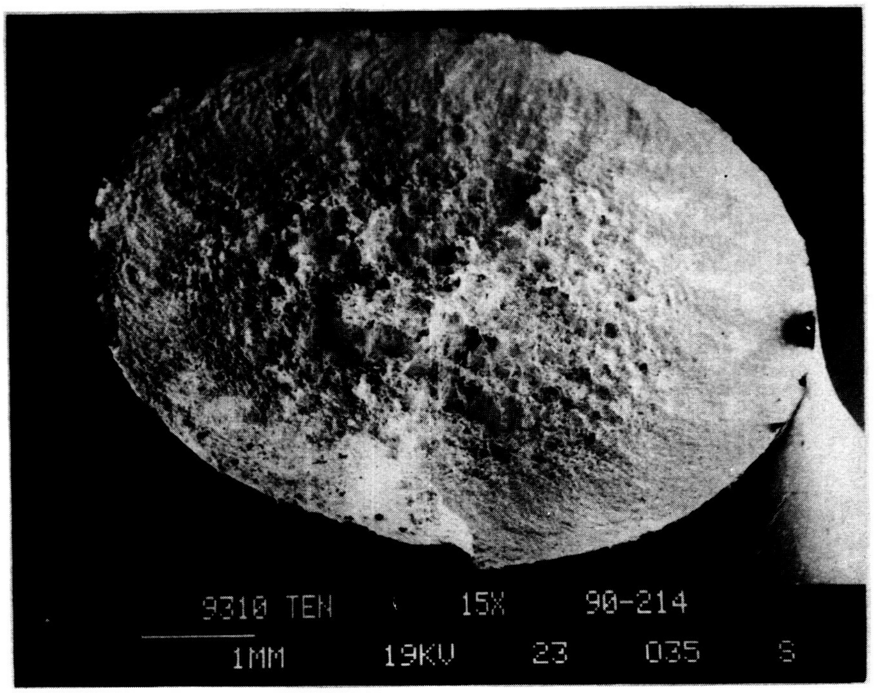


Figure 24B. SEM Views Showing Blocky Intergranular Cracking of a Carburized AISI 9310 Steel Specimen Stressed to 345 MPa (50 ksi) and Exposed to 24 Days of Humidity.



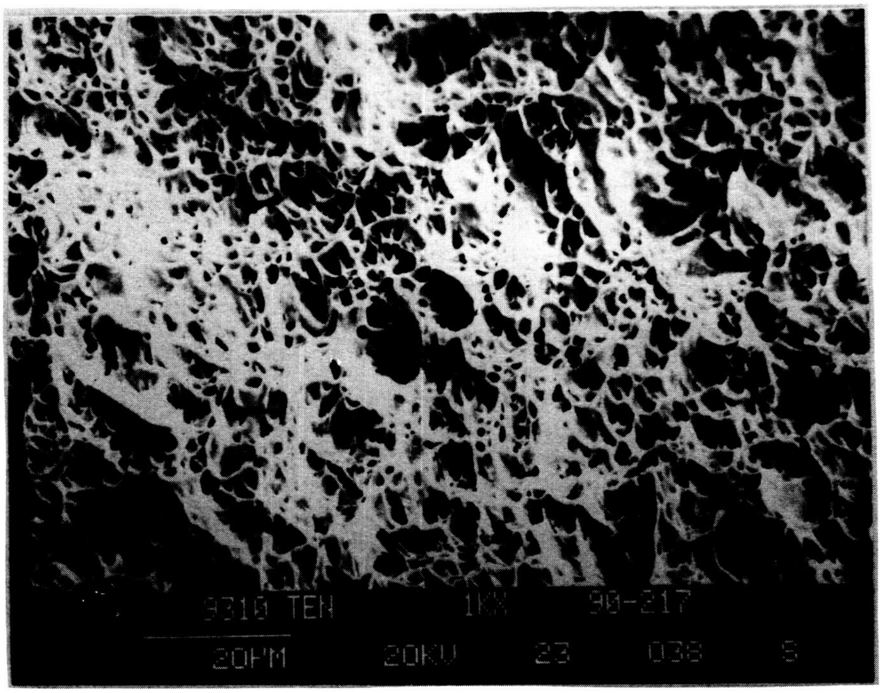
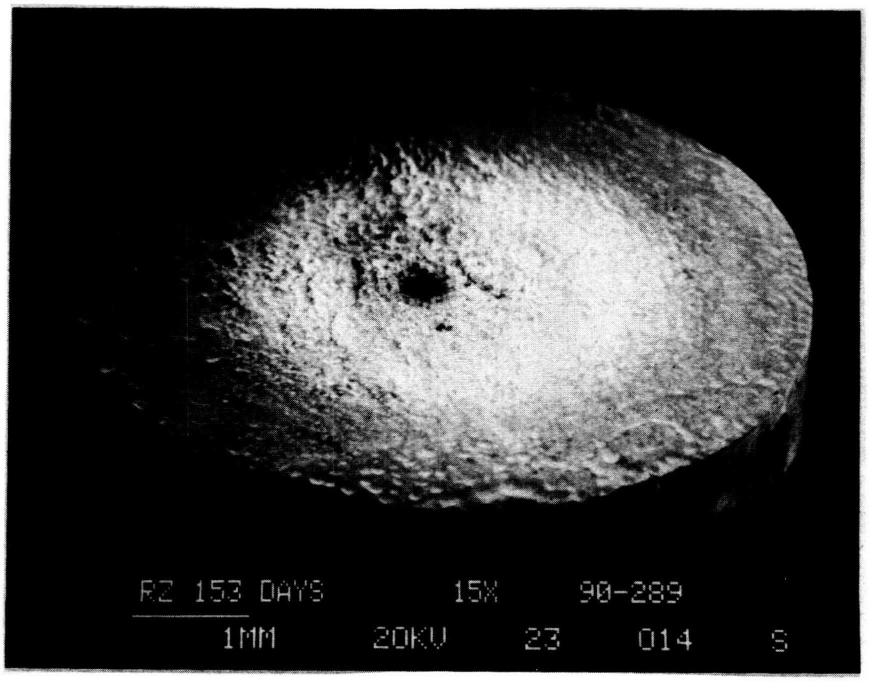


Figure 25. SEM Views of the Fractured Surface of a Carburized AISI 9310 Steel Tensile Specimen Intentionally Tested to Failure With No Exposure to High Humidity.



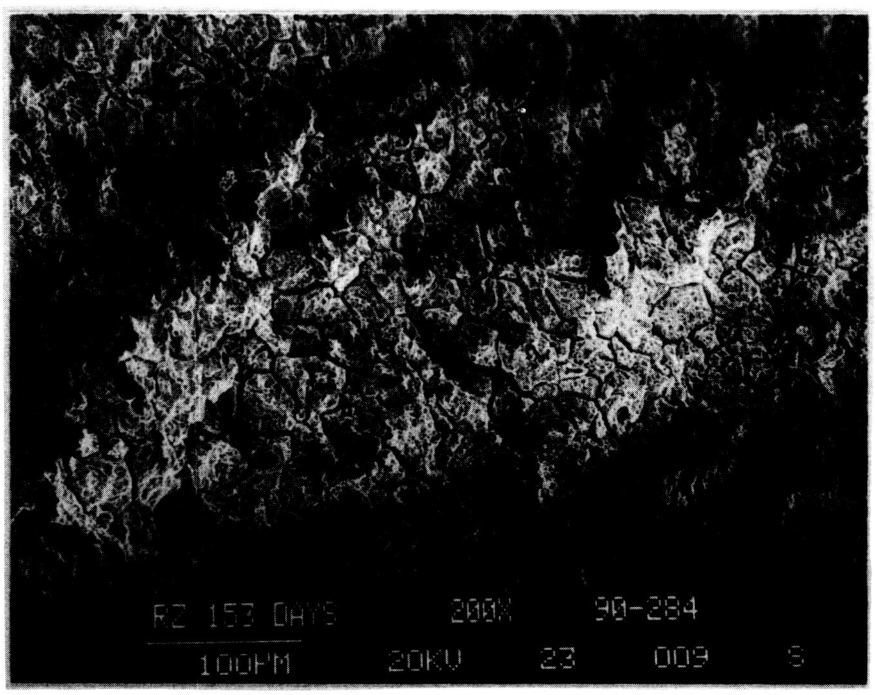


Figure 26A. SEM Views Showing Intergranular Cracking of the Fractured Surface of a Carburized M-50 NiL Specimen Stressed to 517 MPa (75 ksi) and Exposed to 153 Days of Humidity.

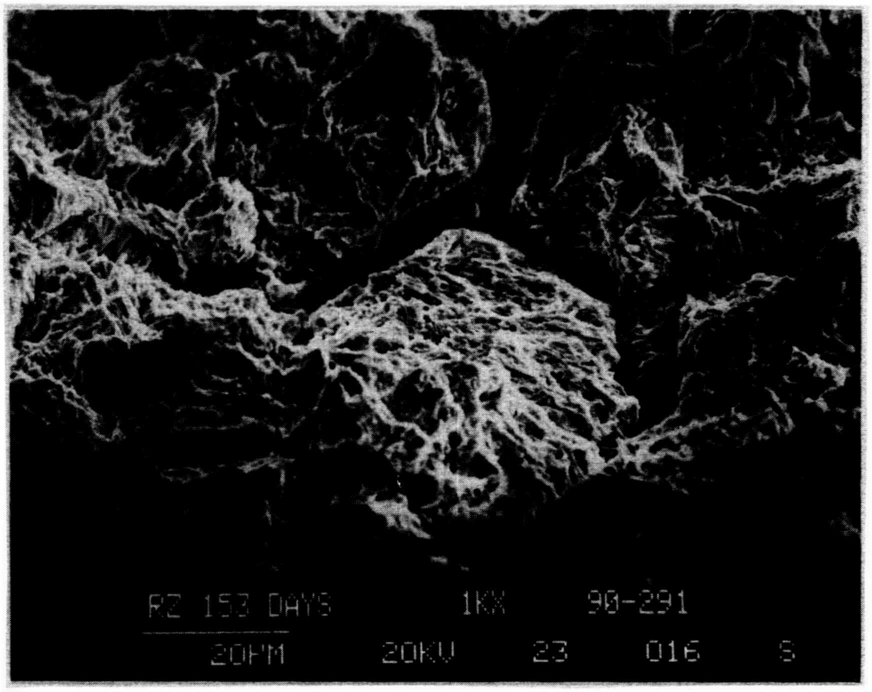


Figure 26B. SEM View Showing Blocky Intergranular Cracking of a Carburized M-50 NiL Specimen Stressed to 517 MPa (75 ksi) and Exposed to 153 Days of Humidity.

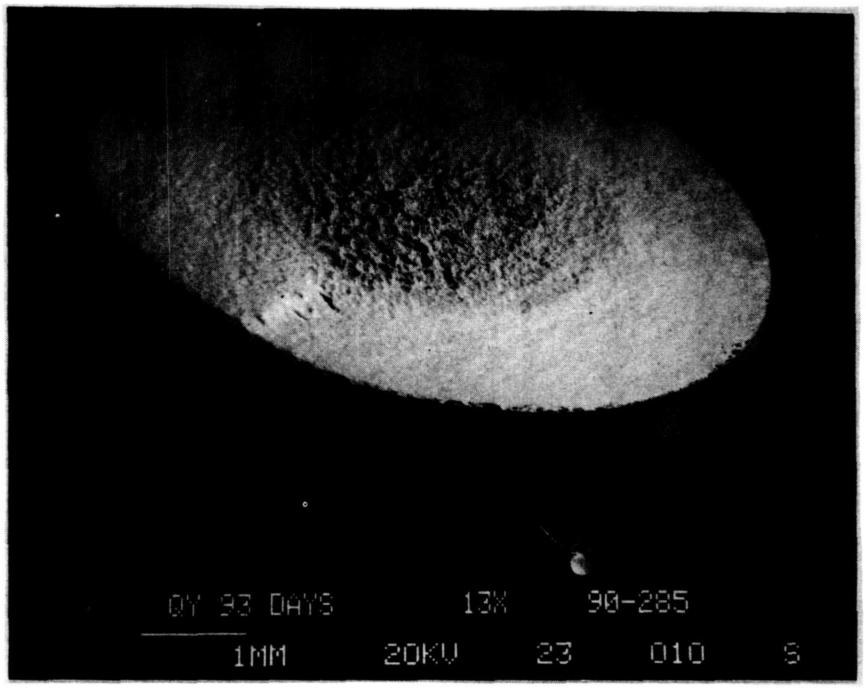


Figure 27A. SEM View Showing the Fractured Surface and Pitting of a Carburized M-50 NiL Specimen Plated With Thin, Dense Chrome, Stressed to 517 MPa (75 ksi), and Exposed to 93 Days of Humidity.

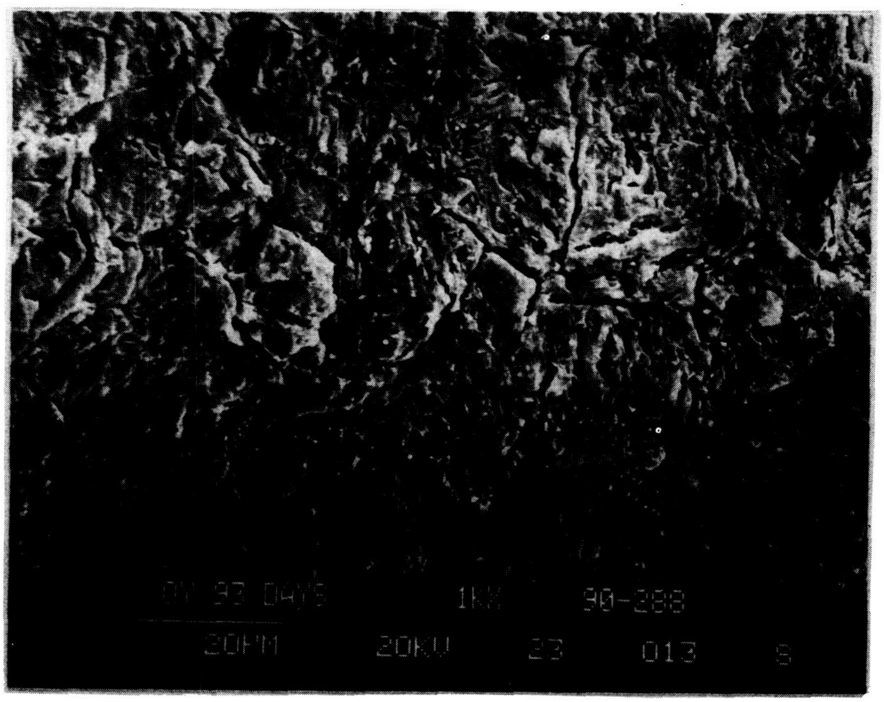
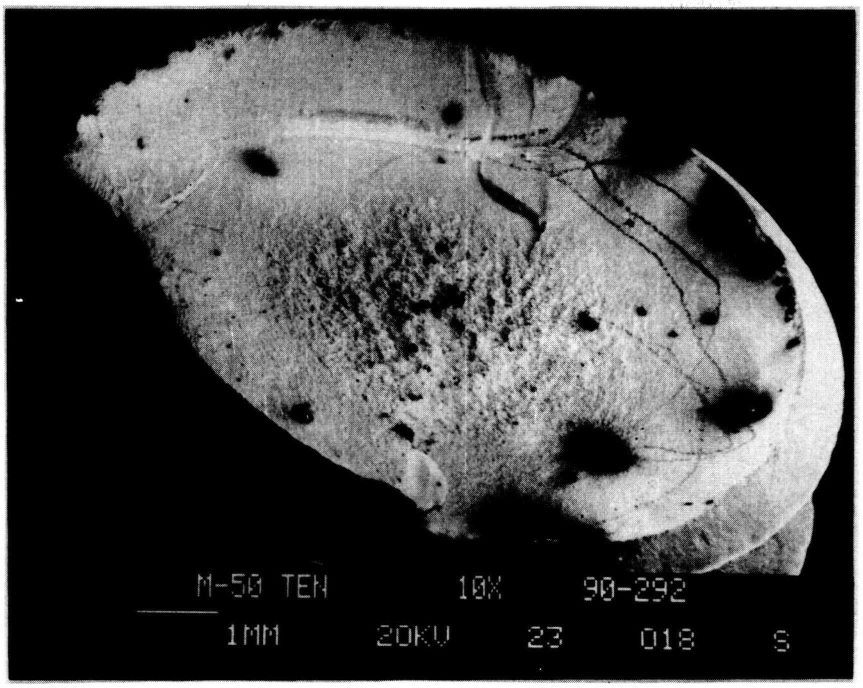


Figure 27B. SEM View Showing Blocky Intergranular Cracking of a Carburized M-50 NiL Specimen Plated With Thin, Dense Chrome, Stressed to 517 MPa (75 ksi), and Exposed to 93 Days of Humidity.



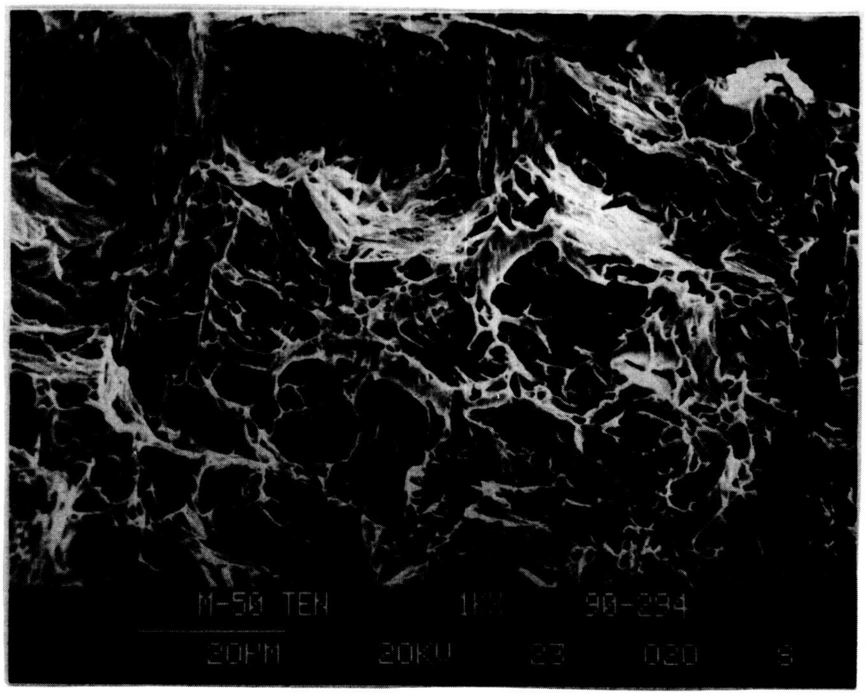


Figure 28. SEM Views of the Fractured Surface of a Carburized M-50 NiL Specimen Tensile Tested to Failure With No Exposure to Humidity.

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16. Abstract

A Stress Corrosion Cracking (SCC) evaluation of carburized AISI 9310 and carburized M-50 NiL steels was undertaken. AISI 9310 is a candidate substitute to 440C for the bearing inner race in the Space Shuttle Main Engine Alternate Turbopump Development Program, and M-50 NiL may also find applications as a bearing alloy. Round tensile specimens of these alloys at several stress levels, as well as corrosion samples of AISI 9310, were exposed to 100-percent relative humidity at 38 °C (100 °F). The maximum tensile stresses that produced no SCC failures in 1 year of exposure were 172 MPa (25 ksi) for AISI 9310 and 345 MPa (50 ksi) for M-50 NiL. Each AISI 9310 steel fracture showed a circumferential crack between the case and the core. Both alloys developed rust on the surface and pitting; however, AISI 9310 rusted to a greater extent than M-50 NiL. Thin, Dense Chrome (TDC) was also evaluated in this program as a corrosion barrier alternative, however, its protection was minimal. Corrosion spots visible to the naked eye appeared in less than 5 days of exposure. Although TDC plating on test specimens prevented the intensive corrosion attack which occurred in bare samples after a long time exposure, the TDC plating did not offer sufficient protection to avoid failures. The results obtained in this evaluation must be carefully considered when designing bearing components made of these materials.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Stress Corrosion; Bearing Alloys; Case Hardened Steels; AISI 9310 Steel; M50-NiL Steel; Thin, Dense Chrome; Space Shuttle Main Engine; Alternate Turbopump	For U.S. Government Agencies and U.S. Government Agency Contractors Only Subject Category: 26

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